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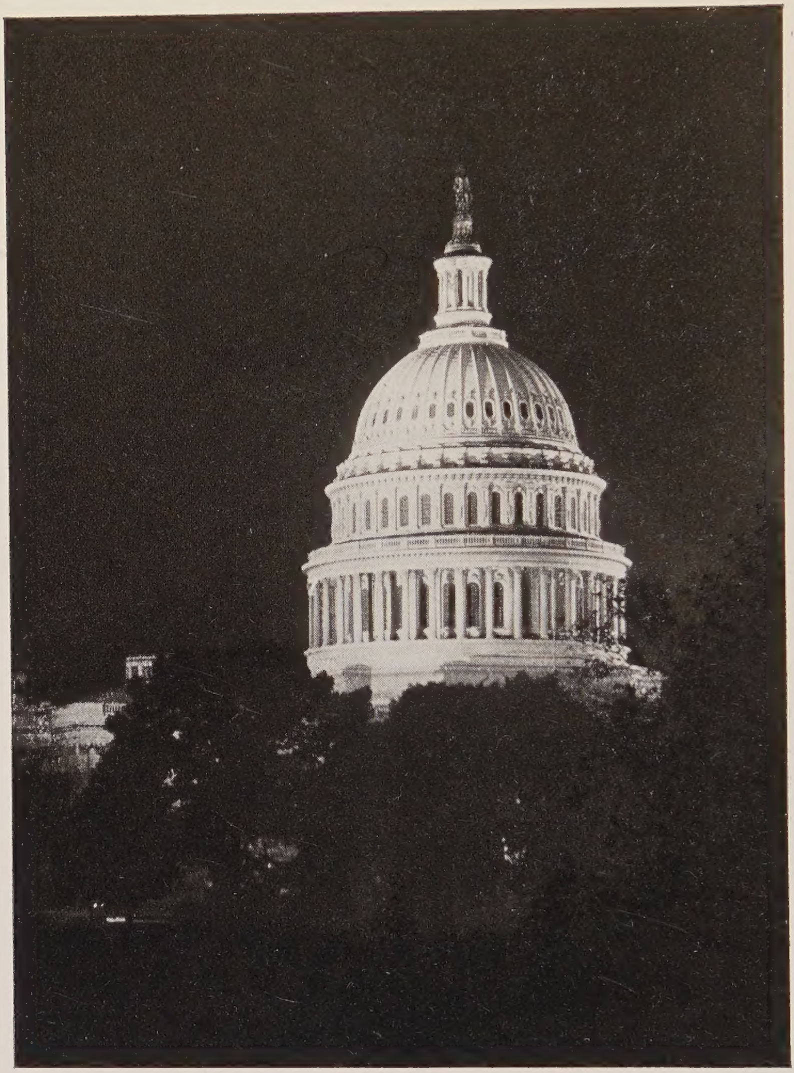

Photo by S. W. Attwell, Teddington.

FLOODLIGHTING OF THE CAPITOL, WASHINGTON, U.S.A.

MODERN ELECTRICAL ILLUMINATION

BY

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WITH NUMEROUS ILLUSTRATIONS
AND DIAGRAMS

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DEDICATED TO

THE CAUSE OF 'BETTER LIGHTING'

FOREWORD

There is no doubt that future progress in commercial and industrial fields will depend in no small measure upon the extensive use of electricity for lighting purposes. The research work carried out by the Authors on the effect of illumination on the eye proves beyond doubt that the eye functions more readily under higher intensities of light; the conclusion to be arrived at is that, with high intensities of light in industrial interiors, production will be increased and spoilage decreased—and this for no increase in production costs.

From a commercial point of view good illumination in shops and stores is essential to progress. Well-illuminated displays in show windows and abundant light of the right kind in interiors enable goods to be seen at their best and examined in comfort. The cost of good lighting is so small a proportion of the total overhead expenses of an establishment, and the return in the way of better business is so great, that commercial establishments to be successful must have ideal lighting.

The traffic problem throughout the country is, at the moment, most acute. I am of opinion that better lighting on main and arterial roads will go far to ease this state of affairs. The object for which a good road is made is defeated if its use is limited by daylight. It is only by transport on well-illuminated roads that traffic at night time can be made safe; it is in this way that congestion during daylight hours can be relieved.

Good lighting is also an essential of our social life. No home can be really homelike without good lighting; a badly lighted theatre is not attractive, and the club and hotel are not comfortable if abundant illumination is not provided, and so on.

This work of the Authors covers a very wide field, since it deals with almost every form of commercial, industrial, and social illumination. The research work carried out, and the data compiled, constitute a valuable contribution to the science of illumination.

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Past President, The Institution of Electrical Engineers.

PREFACE

GOOD lighting involves more than the provision of light. Electric light is an effect, the cause of which is the application of electrical energy to a circuit consisting of wires, switches, and electric lamps. The effect can be good, bad, or indifferent, according to the methods adopted to control the light.

At the beginning of the electric lighting era, the advantages of the new illuminant were quickly realized. It was so convenient to instal, and so much more mobile in its adaptation than all previous light sources, that it was used indiscriminately. A lamp was considered merely as a source of light, and no attention was paid to the elimination of glare and harsh shadows, to the essentials of correct height and spacing, or to the necessity for careful consideration in the choice of reflecting or diffusing equipment.

So many inefficient installations of electric lighting still exist in this country that the uninitiated are likely to model new installations upon old-fashioned lines. This must be prevented, because inefficient installations are not only wasteful but harmful. In this work we have put forward those principles which we consider to be the essentials of correct lighting practice, have advocated that which should be adopted, and have pointed out errors which should be avoided.

We are indebted to Mr. Lionel Lawrence, Director of the School of Optics, for his kindness in allowing us to use several illustrations of the eye, and the text explaining them, from his very excellent book, *Visual Optics*; our work would not be complete without them. We also desire to express our thanks to the Electric Lamp Manufacturers Association of Great Britain, and the British Engineering Standards Association, for permission to reproduce clauses and tables from their specifications, etc., and to the British Electrical Development Association for permission to reproduce photographs illustrating the chapter on Domestic Lighting.

Among others to whom we wish to express our thanks are The Benjamin Electric Co., The Edison-Swan Electric Co., for excellent illustrations of store lighting; The General Electric Co. Ltd., London, who have placed at our disposal their unique collection of photographs; The Research Laboratories of the General Electric Co. Ltd., for curves and data; The Reco Sign Co., U.S.A., and The British Thomson-Houston Co., for illustrations of cathedral lighting; to Mr. S. W. Attwell, O.B.E., M.I.Mech.E., and Mr. C. W. Neadje, for permission to make use of the photographs reproduced in the frontispiece and in Fig. 172 respectively; to Mr. G. W. King, for permission to reproduce the photographs shown in Figs. 210 and 233; to Mr. A. J. Healey, F.R.I.B.A., to Mr. J. L. Stair, U.S.A., and to Mr. G. J. Howling of *The Builder*, for information as to building materials; to Mr. A. W. Mainwaring, for the execution of the effective wash-drawing reproduced in Fig. 185; to Mr. D. A. Hart, Mr. L. E. A. Phillips, Mr. C. W. Bearman, and Mr. W. E. Ballard, for assistance in the preparation of drawings and curves; and to Mr. M. R. Neville, M.C., M.A. (Cantab.), to Mr. T. S. Read, and to Mr. R. Kilpatrick of the University Press, Edinburgh, for their valuable assistance in the reading of the proofs.

Last, but by no means least, we tender our acknowledgments to all to whom they may be due, and our sincere thanks to the many groups of observers in various parts of the country who, at times in very inclement weather, so kindly, and with such patience, placed their services at our disposal during the making of numerous experiments and tests which we found it necessary to carry out.

CYRIL SYLVESTER.
THOMAS E. RITCHIE.

LONDON, 1927.

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CHAPTER I

THE EYE: VISION: ILLUMINATION AND THE EYE

The Eyeball—The First Coat—The Sclerotic—The Cornea—The Second Coat—The Choroid—The Ciliary Body—The Ciliary Processes—The Suspensory Ligament—The Iris—The Stroma—The Retina—Layers of the Retina—The Macula and Fovea—The Ora Serrata—Optic Nerve and Disc—The Sense of Sight—Faculty of Retina—The Optic Nerve—Divisions of Visual Perception—Visual Projection—Pin-hole Demonstration—Visual Acuity—Light Sensation—Illumination and Visibility—The Visual Threshold—Fechner's Law—Measuring the Light Sense—Acuity of Vision—Speed of Discrimination—Tests Carried Out.

THE EYE

To be able to realize to the fullest extent the effect of good and bad illumination upon the eyes it is necessary to consider, to a certain degree, the action of the eye; a certain amount of space will therefore be devoted to this important subject.

The Eyeball (Fig. 1) is an elastic body, about 1 inch in diameter, approximately spherical, but having the segment of a smaller sphere projecting from the front. There are three coats which surround and enclose three transparent media.

THE FIRST COAT (tunica fibrosa) consists of the sclerotic and the cornea, their junction being termed the sclero-corneal margin (sulcus scleræ), where the latter is inserted into the former.

The Sclerotic (sclera) is a tough, opaque, fibrous membrane which surrounds about five-sixths of the globe. It is about 1 mm. thick at the back, thins slightly towards the equator, again to become somewhat thicker at its junction with the cornea. The sclerotic may be regarded as the wall or protective envelope of the eye, its functions being to preserve the contents from injury and to maintain its shape. Its colour is milk-white, but if thin it has a bluish tinge, and if pigmentation is heavy, as in negroes, it is yellowish. It is but poorly supplied with blood-vessels.

The Cornea projects from the front of the sclerotic, and covers the remaining one-sixth of the globe; its tissue is elastic and transparent, and it may be regarded as the window of the eye, through which the light is admitted. The cornea, with the aqueous, forms the first and principal refracting medium in the dioptric system, and the two resemble a segment of a sphere of transparent celluloid. The diameter of the cornea is 12 or 13 mm., but usually its vertical diameter is slightly shorter than the horizontal. Its average thickness is 1 mm., but it is rather thinner at the apex than at the scleral margin. The radius of curvature of its anterior surface is about 8 mm., that of its posterior surface about 6·5 mm., so that the cornea forms a concave meniscus whose index of refraction is taken to be 1·33. The cornea of an infant does not differ much in general dimensions from that of an adult.

The cornea has the following layers :—

1. The outer, or epithelial (epithelium), which is continuous with the epithelial layer of the conjunctiva.

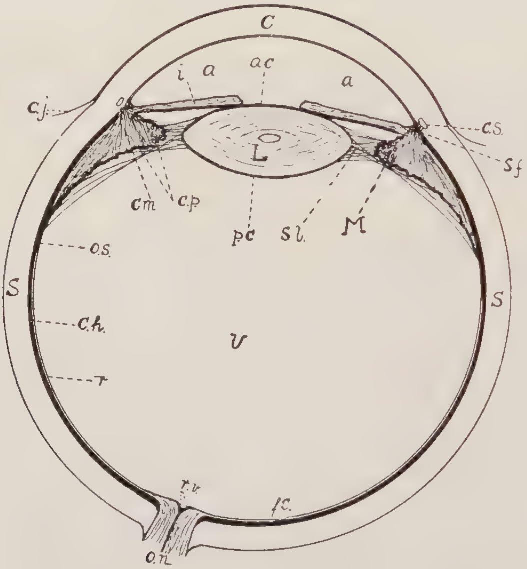

Fig. 1.—Horizontal Section of the Right Eye (Diagrammatic).

aa, aqueous ; *v*, vitreous ; *L*, crystalline ; *C*, cornea ; *S*, sclerotic ; *ch*, choroid ; *r*, retina ; *cm*, ciliary muscle ; *cp*, ciliary processes ; *M*, Müller's ring ; *fc*, fovea centralis ; *i*, iris ; *sl*, suspensory ligament ; *sf*, spaces of Fontana and pectinate ligament ; *cs*, canal of Schlemm ; *ac*, anterior capsule of lens ; *pc*, posterior of capsule of lens ; *cj*, conjunctiva ; *on*, optic nerve ; *os*, ora serrata ; *rv*, entrance of retinal vessels.

2. Bowman's membrane (lamina elastica anterior), an incomplete transparent layer.

3. The middle, or true corneal (substantia propria), which occupies the greater part of the corneal thickness.

4. The internal, or membrane of Descemet (lamina elastica posterior), which is a highly elastic layer, lined internally by cells continuous with those on the front surface of the iris.

These cells are by some regarded as forming a fifth layer (endothelium).

The cornea has no blood-vessels in its substance, but is nourished by lymph flowing between the laminæ of the middle layer. It is richly supplied with fine nerve-endings, which render it highly sensitive to touch and to foreign bodies.

THE SECOND COAT (tunica vasculosa) consists of the choroid, the ciliary body, and the iris, and is sometimes called the uveal tract or coat.

The Choroid (choroidea) lines the sclerotic, and is composed of connective tissue, blood-vessels, and dark-brown pigment cells. The processes of the latter, in the presence of light, elongate and contract, and are evidently connected with vision, since they exist, to a greater or less degree, in all animals which have light-perceiving organs. The chief function of the choroid is, however, probably nutritive, supplying, together with the ciliary body, nourishment for the whole of the eyeball. The pigment of the choroid does not extend beyond the layer of large blood-vessels.

The layers of the choroid from the retina backwards are :—

1. The limiting layer, or membrane of Bruch (lamina basalis), a transparent, colourless, structureless layer which lies in close proximity to the pigment layer of the retina.

2. The true choroid (substantia propria), which is divided into
   (*a*) The layer of capillaries (lamina capillaris).
   (*b*) The layer of large blood-vessels (lamina vasculosa).

3. The external pigment or fusca layer (lamina suprachoroidea), which is next to the sclerotic.

The choroid is attached to the sclerotic at the optic disc and ciliary region. A lymph space (spatium perichoroideæ) lies between the two coats.

The Ciliary Body (Fig. 2) (corpus ciliare) commences at the ora serrata and terminates at the iris and crystalline lens. It is the anterior prolongation of the retina and choroid, and is about 8 mm. in length over all. It is composed of the muscle, the process, and the suspensory ligament.

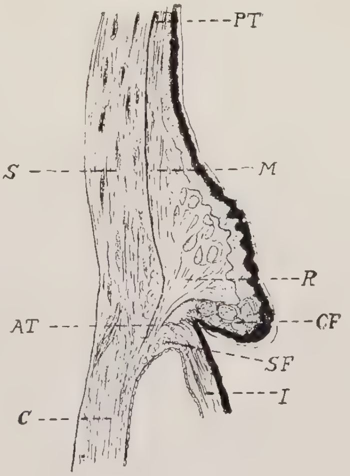

FIG. 2.—THE CILIARY BODY.

S, sclerotic; *C*, cornea; *I*, iris: *SF*, spaces of Fontana; *AT*, anterior tendon of the ciliary muscle; *CF*, circular fibres; *R*, radiating fibres; *M*, meridional fibres; *PT*, posterior tendon of muscle.

The Ciliary Muscle (musculus ciliaris) consists mainly of two parts : *i.e.* the radiator (fibræ meridionales), which arises from the sclero-corneal margin and, passing backwards, is inserted into the choroid ; and the sphincter (Müller's ring), whose fibres (fibræ circulares) are at right angles to those of the radiator; these form a ring which surrounds the periphery of the lens a short distance from its edge. The ciliary muscle lies between the ciliary processes and the sclerotic, and immediately beyond the base of the iris. It is about 1 mm. in diameter at its thickest part, and about 3·5 mm. long.

The Ciliary Processes (processus ciliaris) are a direct prolongation of the choroid, forming a convoluted gland, richly supplied with blood-vessels, and covered with secreting cells and dense black pigment. The function of these cells is to secrete a fluid to nourish the crystalline and vitreous humour, and to replenish the aqueous.

The Suspensory Ligament, or zonule of Zinn (zonula ciliaris), consists of filaments arising from the membrana limitans interna at the ora serrata and from the ciliary processes. They are attached to the capsule of the crystalline at its periphery both in front and behind, and the triangular space thus formed at the margin of the crystalline by the suspensory ligament is called the canal of Petit (spatia zonularia). The ligament is not a complete membrane, and the aqueous percolates through its filaments.

The Iris is a thin, highly pigmented, coloured membrane whose anterior surface is visible through the cornea behind which it lies, and from which it is separated by the aqueous humour. In the centre there is a circular aperture called the pupil, through which light enters the eye, the pupillary margin lying against the front surface of the crystalline, by which it is supported and steadied. Thus the centre of the iris projects slightly beyond the periphery.

The Stroma, or iris proper, consists of blood-vessels and connective tissue. On its anterior surface, up to the pupillary margin, there is a layer of cells continuous with those lining the posterior surface of the cornea, while the posterior surface is thickly covered with black pigment cells continuous with those lining the ciliary processes. The quantity of pigmentation causes the iris to be light or dark, and gives to the eye its characteristic coloration. The iris is divided by a ring (circulus minor) into two zones, which in some eyes are markedly different in colour.

The iris contains straight fibres (dilatator pupillæ) radiating from the centre, which dilate the pupil when the opposing circular fibres are inactive, the latter constituting a circular contractile muscular ring, called the sphincter pupillæ, which surrounds the pupillary edge of the iris. The circular fibres are undoubtedly muscular, but the radiating fibres probably consist of elastic tissue kept slightly on the stretch by the sphincter. The diameter of the iris is about 12 mm., but that of the pupil varies, the average being, in ordinary light, say 3 or 4 mm. The width of the iritic band thus varies as to its diameter inversely with the size of the pupil, and is about equal to the latter in moderate illumination. It is usually rather narrower on the nasal side.

The Fundus is the anterior of the back of the eye, as seen through the transparent cornea and humours with the aid of an ophthalmoscope, the light passing into and out from the eye through the pupil. It is seen as a bright red field with blood-vessels passing over it, its most conspicuous landmark being the whitish optic disc. The apparent size of any parts of the fundus of the eye, as seen ophthalmoscopically, is delusive, they being seen highly magnified.

THE RETINA, or third coat, consists of a network of fibres and cells in direct connection with the optic nerve and adapted to receive the impressions of light. It lies posterior to the vitreous and anterior to the choroid; to the latter, except at the ora serrata, it is attached by the pressure of the internal contents of the eye. It contains various layers, the most important being that of the rods and cones, and the hexagonal pigment-cell layer, which secretes the visual purple, a substance intimately connected with vision. These, too, may be considered the receptive layers of the retina, since they are specially influenced by the action of incident light. The rods and cones are packed close together with their free ends touching the hexagonal pigment layer, and are turned away from the cornea, an arrangement apparently the most favourable for receiving the stimulus, whatever be the change—chemical, electrical, mechanical, or otherwise—which results in the conversion of light into some other form of energy capable of transmission by the retinal and optic nerve fibres to the brain, so that sight occurs. If light is to do work it must be absorbed.

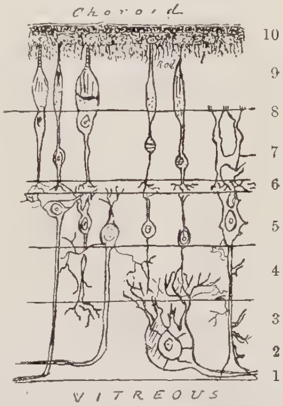

FIG. 3.—DRAWING MADE FROM A MICROSCOPIC SECTION OF THE RETINA.

1, membrana limitans interna; 2, nerve-fibre layer; 3, layer of ganglion cells; 4, internal molecular layer; 5, internal nuclear layer; 6, external molecular layer; 7, external nuclear layer; 8, membrana limitans externa; 9, bacillary layer (rods and cones); 10, hexagonal pigment layer.

The retina is transparent and invisible in health, the red colour of the fundus being due to the reflected light from the pigment layer, the choroidal pigment, and the blood-vessels. Its thickness varies from ·1 mm. to ·3 or ·4 mm., the average being ·15 or ·2 mm.

The Layers of the Retina from the vitreous backwards are as follows:—

1. Internal limiting membrane. A thin, almost structureless membrane, whose inner surface lies in contact with the vitreous humour.

2. Nerve-fibre layer. A sheet of nerve fibres which are the direct continuations of those of the optic nerve.

3. Nerve-cell (ganglionic) layer. The retinal blood-vessels, which are the branches of the central artery and vein, lie in this layer.

4. Internal molecular or plexiform layer. A fine network of fibres, which shut off the large blood-vessels from the posterior layers.

5. Internal granular or nuclear layer.

6. External molecular or plexiform layer. Similar to No. 4. It shuts off communication with the capillaries and supports the inner terminals of the rods and cones.

6*a*. The paramacular or retinal plexus border layer. A narrow, well-defined layer of fibres discovered in the retinæ of man and most monkeys, and so named by Lindsay Johnson. It is in line with the front of the fovea, and extends only over and around the macular area.

7. External granular or nuclear layer.

8. External limiting membrane. A thin, perforated membrane supporting and insulating the rods and cones.

9. Bacillary layer, or layer of rods and cones. The receptive terminals of the optic nerve, on the ends of which the image of an external object is supposed to be formed. The cones are shorter and slightly thicker than the rods.

10. Hexagonal pigment layer. A glandular layer secreting the visual purple, in which the outer parts of the rods and the tips of the cones are embedded. This lies adjacent to the membrane of Bruch of the choroid.

Layers 1 and 8 are connected by vertical fibres which run at right angles to them, thus supporting the intermediate layers; 2, 3, and probably 5 and 7, form the conducting apparatus; 9 and 10 are receptive, while 10 has a secreting function as well.

The Macula and Fovea.—At the back of the eye, its centre on the visual axis, situated about 1·25 mm. to the temporal side of the posterior pole, is the most sensitive part of the retina termed the yellow spot, or macula lutea, within which all clear vision lies. It is difficult to see with the ophthalmoscope, but may appear of slightly different colour from the other portions of the fundus, more free from blood-vessels, and sometimes there can be seen a bright reflex ring surrounding it. The macular area is round, or slightly elliptical with the longer diameter horizontal; it is about 2·5 mm. in diameter. The true macula is about 1 mm. in diameter, and is the seat of most distinct vision. In its centre there is a minute pit, or depression, about 0·25 mm. in diameter, called from its position the fovea centralis, and this part consists entirely of narrow cone fibres packed closely together, where vision is most acute. The receptive faculty of the retina diminishes from the fovea to the ora serrata.

The Ora Serrata is the peripheral termination of the retina, and lies a little anterior to the equator of the eye, near to where the choroid proper merges into the ciliary processes.

The Optic Nerve and Disc.—The optic nerve (nervus opticus) enters the eye through the sclerotic at the lamina cribrosa, situated at the back of the globe somewhat to the nasal side of the posterior pole. The head of the nerve, called the optic disc, can be seen with the ophthalmoscope, or in the eye when dissected, as a round or vertically oval pinkish-white disc, from 2 to 2·5 mm. in diameter. The retina is absent at the disc, so that the latter is insensitive to light and is therefore called the blind spot. The sheath of the optic nerve is continuous with the sclerotic itself. From the centre of the optic disc the retinal veins and arteries radiate over the fundus, and around the disc there may be often seen incomplete rings or crescents of white, bare sclerotic and of black choroidal pigment. Its centre (excavatio) is slightly lower and its outer portion (papilla) slightly higher than the surrounding retina.

Vision

The Sense of Sight.—The eye is said to be the first sense organ developed in the embryo. After touch it is also the most universally distributed sense, existing, except in the very lowest forms of life, throughout the animal kingdom. Sight is the chief factor in the education and intellectual development of man ; by its aid the form, colour, size, distance, position, and characteristic details of objects become known. The mental process of projecting upright images from inverted retinal images is natural, it being apparently present in earliest infancy, and the faculty is never lost, unless, indeed, sight itself is lost.

The sense of light lies, not in the eye, but in the brain. The retinal stimulus is interpreted in the form of a projected virtual mental image of the object, the sensation excited by the impingement of the light rays on the retina having been communicated to the brain by means of the fibres of the optic nerve. From experience and education the rays are referred back to a distance closely coinciding with that which they travelled before entering the eye. Thus the projected mental image usually corresponds in every respect—in position, distance, size, etc.—with the object viewed. It is not the object, but the mental picture, that is seen, although it is commonly said that one sees the object itself, and this is certainly the most convenient way of expressing the phenomenon of vision.

Faculty of Retina.—The retina has a receptive faculty ; it does not see, but merely receives the impression from which the mental appreciation of an external object results. Sight is a faculty of the brain, but, since clearness of vision is directly proportional to the number of cones existent in that part of the retina on which the image is formed, it is customary to refer to the perceptive faculty of the retina.

The Optic Nerve.—The optic nerve is incapable of conveying any sensation other than that of light. If it be touched or injured, nothing but the sensation of a flash of light results.

The optic nerves, after passing through apertures at the back of their corresponding orbits, meet each other at the chiasma in the median plane immediately beneath the brain, and many of the fibres cross (decussate) over to the opposite nerve, so that, after meeting, each is composed partly of its own fibres and partly of the fibres of the opposite nerve. The bundles of fibres, now termed optic tracts, proceed thence to the brain (Fig. 4).

The cerebral ends of the nerve fibres do not seem to be arranged in regular order, as are their other ends at the retina, but apparently this does not interfere with the formation of a correct mental picture of an external object. Each retinal terminal receives a stimulus from its corresponding point on the object, such stimulus being then transmitted to the brain cell at the other end of the fibre; this being done, the individual sensations are assigned their correct position in the mental picture. The exact process of mental interpretation is, however, unknown, and when the light wave reaches the retina our knowledge with regard to vision ceases. We do not know the nature of the force which conveys the sensation, nor can we assign their respective functions to the known centres of vision. We might regard the mental eye as consisting of the two eyes in Fig. 4 combined with M in the centre, and the two sides being right and left respectively.

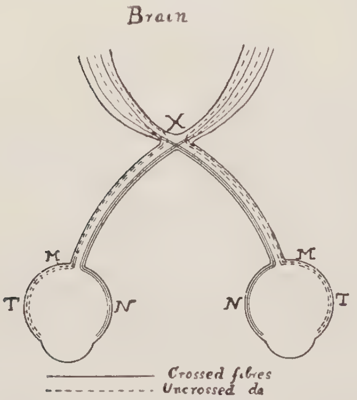

Fig. 4.—Diagram illustrating the Course of the Fibres of the Optic Nerves from the Eyes to the Brain.

The fibres belonging to the nasal half of the fundus cross over, at the chiasma, to the opposite hemisphere of the brain. The fibres which are distributed over the temporal half of each eye are confined to its corresponding side of the brain. Thus the right halves of the two visual fields go to the right hemisphere, while the two left halves pass to the left.

N, Nasal; *T*, temporal; *X*, chiasma; *MM*, maculæ.

Divisions of Visual Perception.—The sense of sight may be divided into three classes of perception, viz. light, form, and colour.

The Light Sense is the faculty of distinguishing illumination and its gradations of intensity. The distinction between light and darkness is the lowest degree of this faculty, and if it be absent there is complete blindness. On the light sense depends the power of the retina to adapt itself to various degrees of illumination. It forms the only visual sense in many of the lower forms of animal life.

The Form Sense is the faculty of recognizing outline or shape; it requires a transparent refracting body to collect the light and form a real image, a conducting apparatus, and a sensory organ.

The Colour Sense is the highest development of vision, and enables the eye to appreciate light waves of different frequencies.

In general, of course, all three divisions of visual perception are present; but the second or third, or both, or even all three, may be lacking in a particular case.

Visual Projection.—The mental projection of each point of the image is outwards through the nodal point, in the direction of the axial ray of the incident beam of light producing that point in the retinal image.

The position of the brain image in space is according to the particular part of the retina on which light falls, and not according to the original direction of the light. Thus, if the retinal image be formed by rays reflected from a plane mirror, the brain picture is conceived to be behind the mirror, at the same distance from its surface as the object itself is in front of it. One can see in a mirror (and therefore in front of him) the images of objects actually situated behind his back, for the rays, having entered the eye from the face of the mirror, are mentally projected in that direction.

If the retinal image be formed by rays refracted by a prism, the object appears shifted towards the edge, because the rays, after refraction, being turned towards the base, enter the eye as if they came from an object situated in a position nearer the edge, and are mentally referred back accordingly. Again, an object viewed through a convex or concave lens is seen respectively larger or smaller, the light diverging from each object point being in the first case less divergent after refraction and therefore projected to a greater distance, and in the second case more divergent and therefore projected to a shorter distance. When the image and the object do not correspond in position, the image is said to be seen. When they do correspond, the object is said to be seen.

The faculty of visual projection is inherent, although with respect to distance it appears to be acquired. A baby obviously makes mistakes in the distance of an object he wishes to grasp, and a person who sees things under new conditions, as through lenses for the first time, may misjudge the distance of an object, but he will never conceive it as upside down or displaced laterally. One who is in the habit of seeing things under certain conditions judges much better their distance than one to whom such conditions are new. We can obtain inversion by viewing an object through a strong convex lens held some distance in front of the eye; we then see in the air a real inverted image of the original object. From this real image the light diverges and produces on the retina an upright image, so that the mental interpretation is that of an inverted impression of the original object. The same occurs if a landscape be observed through an astronomical telescope, or in a concave mirror held sufficiently far away from the observer's eye, or through an inverting prism.

The law of visual projection seems to be quite natural, even if we disregard the mental and consider the matter from a physical aspect. There is a lens so placed that the real inverted image formed by it lies on a mirror which reflects the light back to form another real upright image coinciding with the object from which the light originally proceeded. If the retinal image were a luminous object, its image would have the distance, size, and uprightness of the object ; the two are conjugates. The original object, a lantern-slide reproduction of it, and the projected picture of the slide form a reasonably good illustration.

Pin-hole Demonstration.—The pin-hole can be employed to prove the law of projection, and that upright vision is a result of inversion of the real retinal image. Let D (Fig. 5) be the pin-hole held close to the eye at about F_1 ; then the light passing through the aperture is approximately parallel on reaching the retina, and forms thereon a disc of illumination *ab* about the size of the pupil. The projected image of *ab* is represented by *b′a′*, and if a pin P be placed between D and the eye an upright shadow will be cast on the retina. This shadow is projected as P_1, an inverted image of the pin, and is seen on the opposite side to the actual position of the latter.

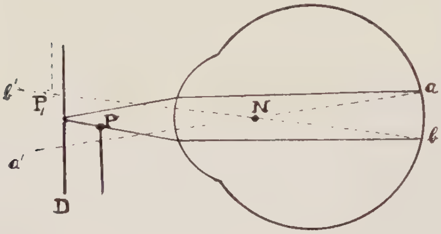

FIG 5.

Visual Acuity is the measure of the faculty of receiving, transmitting, and mentally interpreting the retinal impressions. It depends on the transparency of the media, the nervous functions of the retina and optic nerve, and the interpretative faculty of the brain. Also, to a smaller degree, it depends on the size of the retinal image, and therefore on the distance between the nodal point and the retina. Strictly, the acuity of an eye is its visual power under best conditions—that is, improved, if required, by corrective lenses, so that refractive power is not included in the governing factors.

Light Sensation.—It is supposed that the sensation of light is due to the stimulus given to the terminals of the rods, and discrimination between differences of detail to that given to the cones. The cones are much more abundant than the rods at the highly sensitive macula, and at the fovea the rods are entirely absent. Moreover, the foveal and macular cones are smaller than those in the peripheral regions ; on the other hand, towards the ora serrata, where there is almost complete absence of perception of details, the cones are comparatively few in number ; hence the deduction that acute vision depends on the cones, and light appreciation rather on the rods. The fovea is not the most sensitive part of the retina to very feeble luminants or objects of feeble luminosity ; these appear to be better seen by means of the rods than of the cones. For instance, a very faint star, invisible at the fovea, can be seen if its image falls a little to one side of it. Many nocturnal animals have few or no cones at all.

Illumination and Visibility.—The visibility of an object increases with the luminosity up to a certain point, beyond which the intensity of the light causes dazzling and confusion from internal reflections and intraocular haze due to the imperfectly transparent media of the eye, with consequent blurring of the image. The effect is increased if the light is very powerful, because a certain amount passes through the iris and sclerotic. One cannot see the sun unless the intensity of the light be greatly modified by smoked glasses, or fog, or otherwise; intensely brilliant headlights on motor cars, etc., simply cause confusion, whereas less powerful ones would be more efficacious. A body is best seen if it is sufficiently luminous or illuminated and in good contrast with its surroundings.

A self-luminous body is seen darker if the surrounding light is more powerful than that of the body; points like stars are invisible in the daytime. A candle flame is barely visible in bright sunlight, but can be seen a very long distance away on a dark night.

Habit, however, enables a person to see under conditions of illumination which would be impossible for those unaccustomed to them. Even in ordinary circumstances a sudden change from brightness to partial obscurity, or *vice versa*, makes clear vision impossible, as when one passes from bright light into a darkened room, or from the latter to the former, although in a few minutes the eyes, becoming accustomed to the altered illumination, see with sufficient distinctness.

The Visual Threshold.—The lowest degree of visual acuity consists of the bare appreciation of the difference between light and darkness; one possessing less than this is quite blind. The lowest limit of light that can be observed by an eye is termed its light threshold, and this varies in different people. It can be represented, for a normal eye, by a piece of white paper feebly illuminated and placed about 200 metres away on a black background.

Fechner's Law.—According to Fechner, the least appreciable increase of stimulus follows a definite law, which holds good for all sensations, and, as regards light, a difference of about 1 per cent. in the intensities of two sources of illumination can be just appreciated. This law, however, only holds true for light of medium intensity. Slight stimuli of any kind are not noticed, so that differences between feeble lights cannot be perceived by the eye at all. Very intense stimuli produce a similar result, for, however much they are increased, no further increment in intensity can be detected. In very feeble or in very intense light all things appear equally dark or light respectively.

Difference in size of two bodies can be appreciated if it amounts to some $2\frac{1}{2}$ per cent. This, again, does not apply in the case of very large or very small bodies.

Measuring the Light Sense.—Forster's photometer, used for this purpose, consists of a box blackened inside and with two openings for the observer's eyes. At the back of the chamber, opposite the sight-holes, there is a series of white stripes on the black ground. A light is placed behind an aperture of variable size, so that the stripes are illuminated to any desired degree. The person to be tested looks through the aperture and gazes into darkness for half a minute or so. The aperture is then slowly opened until the stripes can just be seen, and a scale connected with the aperture shows the degree of light sense. Test types or figures can be substituted for the stripes, and coloured plates can be placed in front of the aperture, so that the light necessary for colour perception can be measured.

The light sense can also be tested by light grey letters, of graduated sizes and shades, on a black background, placed at such a distance that they can just be seen by a normal eye; if the light sense is deficient, the letters must be approached in order that they may be seen. Or it can be tested by a photometer in which two discs are viewed, and the one is made darker by a smoked glass; the smallest appreciable difference in the appearance of the two discs is the light difference (L.D.). If the darkened disc be looked at and gradually lightened, the smallest degree of illumination noted represents the light minimum (L.M.).

ILLUMINATION AND THE EYE

The functioning of the eye is governed to a very large degree by the intensity of light by which objects are viewed. If an observer and an object are placed in a dark room, the object cannot be seen. If, however, light of low intensity is brought into the room, the object can be seen dimly. If the light intensity is increased a little, the object can be seen more clearly, until, when the intensity is sufficiently high, every detail of the object can be seen. In attempts to discover the actual effects of light of various intensities upon the eye, the authors have carried out a number of experiments. The results obtained are submitted herewith for the information of the reader.

The first test was a failure merely because incorrect methods of testing were adopted; we describe this test, and give reasons why it is unreliable, in order that similar methods may be avoided by manufacturers who desire to carry out periodical tests upon their own operators.

In this test 100 turned pieces of steel, $\frac{3}{8}$ inch in diameter, were divided into four groups of different lengths; the lengths were $2\frac{5}{8}$, $2\frac{3}{4}$, $2\frac{7}{8}$, and 3 inches respectively. The pieces were mixed up in a tray, and the test was to place them in their respective groups under various intensities of light. The time taken in each case was checked, but it was found that, several times, the groups were completed more quickly under the lower intensities of light. This was quite contrary to our expectations, and was for a time puzzling, until, when watching one person, it was found that she lifted no fewer than four test-pieces from the tray at once and placed them in their correct group. The problem was solved, because, if a number of test-pieces happened to lie together in the tray, and these were of the same size, there was no need for the eye to discriminate to the same extent as there would be if the observer could see only one test-piece at a time.

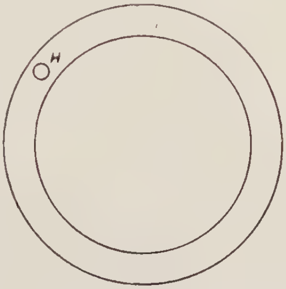

Fig. 6.—Our Original Method of testing Speed of Discrimination.

The method adopted in our speed of discrimination test is quite original and very reliable. We obtained a piece of millboard faced on one side with pearl-grey paper having a reflection factor of 60 per cent. On this was pasted another piece of grey paper cut in the form of an O; the reflection factor of this paper was 73 per cent. The outside diameter of the O was 18 inches and of the inside 14 inches; thus the 'line' of the O was 2 inches wide. In this line a circular hole H (Fig. 6) was cut. When closely examined, a dark disc could be seen in the line of the O.

A hole was then made in the centre of the millboard and the latter was placed over a nail; it was then given a spin, and after it came to rest the disc in the line would point in a certain direction. What the observers had to do was to indicate the direction of the disc from the centre, such as top right, top left, bottom right, bottom left. The time between the stoppage of the disc and the moment the observer spoke (since this was the moment the message was conveyed from the retina to the brain) was carefully checked with a chronometer stop-watch. The minimum intensity of light was 0·4 foot-candle and the maximum intensity was 14 foot-candles. The results of the tests are indicated in graph form at A (Fig. 7).

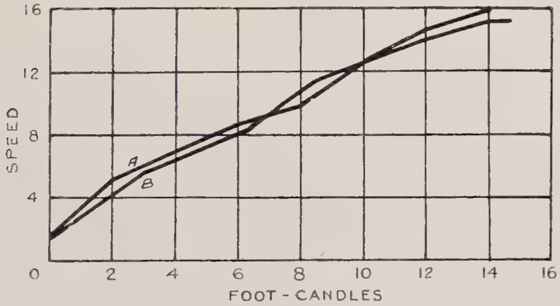

Fig. 7.

As a check against this method we used the cylinder illustrated in Fig. 8. This is an ordinary white cylinder upon which a number of black letters are printed; it is placed upon an ordinary gramophone table, and a lever is used to start and stop it. We fitted a shield on the front with a small aperture at the bottom, so that each time the cylinder was started and stopped different letters were presented at the aperture. The test was to indicate the letters under varying intensities of light. The foot-candle intensities were the same as before, and the results are plotted in Fig. 7, B.

We also carried out a number of tests to determine the acuity of vision. In this test eight cards were used; three of the cards are illustrated on page 15. Each card contains a number of letters made up into words having no meaning; the object of this was to present quite unfamiliar reading to the observers. The cards are printed in different sizes of type, the largest type being on No. 1. The test was carried out on six observers with a minimum intensity of 0·03 foot-candle and a maximum intensity of 16 foot-candles. From the average results, which are shown in Fig. 9, it will be seen that the gain in acuity does not appreciably increase above 6 foot-candles. The printing on the cards was in black ink upon a white matte surface with a reflection factor of 84 per cent.

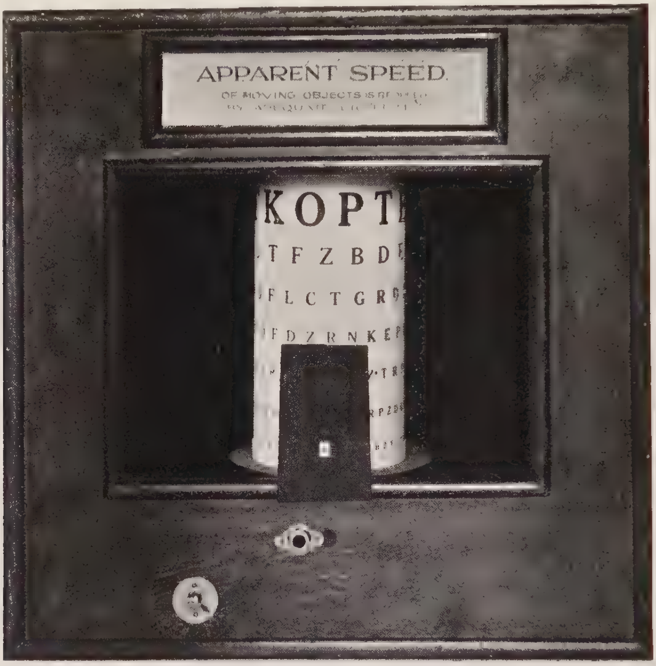

Fig. 8.—Apparatus we used in the Speed of Discrimination Test, as a check against our previous Tests.

These tests prove conclusively that the eye functions better under higher intensities of light. This points to the necessity for good lighting in industrial interiors, where acuity of vision and speed of discrimination are essentials of successful operations.

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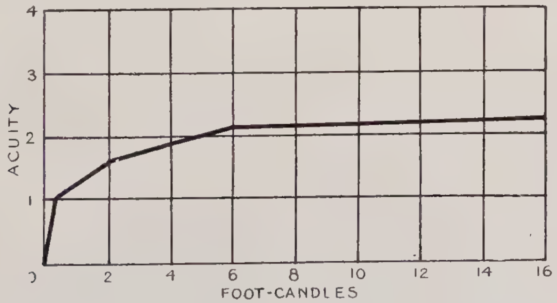

Fig. 9.—Our Results of Tests for Acuity of Vision.

CHAPTER II

COLOUR: COLOUR VISION: LIGHT CONTROL: SHADOWS

Composition of Solar Light—Cause of Colour—Primary and Secondary Colours—Complementary Colours—Spectrum Colours and their Complements—Brightness of Colours—Colours of Bodies—Colours in Pigments—The Mixing of Colours—Qualities of Colours—Coloured Bodies and Lights—Coloured Bodies and Glasses—Superposition of Coloured Glasses—Sensitivity of the Eye to Different Colours—Purkinje's Experiment—Sensitivity to Intensity—Colour Fatigue and After-Images—The Mental Standard of White—Perception of Black—Colour Vision—The Nature of Light—Angles of Incidence and Reflection—Refraction—Newton's Experiment—Curve of Intensity of Light—Wave Lengths—Ångström Units—Diffusion—Direction Lighting—Diffused Lighting—The Cause of Shadows, and their Elimination.

Colour: Colour Vision

Composition of Solar Light. — Solar light, which is white, can be resolved by dispersion into seven distinct colours, viz. red, orange, yellow, green, blue, indigo, and violet. Some authorities omit indigo and consider the spectrum to consist of six main colours, and some even omit the yellow, which colour indeed occupies but a small space in the spectrum. The combination of these colours in correct proportion produces white light.

The sensation of red is produced by comparatively long waves of low frequency, the sensation of violet by short waves of high frequency, while the intermediate colours are produced by wave-lengths and frequencies between these two limits. Wave-lengths beyond certain limits—on both sides—do not excite any sensation of light.

Cause of Colour.—Ethereal waves of certain length and frequency always produce the mental sensation of a definite colour in a person of normal colour-perception. Whether the length of the wave or its frequency, or both, give rise to the definite sensation, and whether the retina or the mind differentiates between the various rays, are points not yet settled. Most colours can be produced also by combining others together.

Primary and Secondary Colours.—It was shown by Young, and confirmed by Helmholtz, that every colour in nature can be obtained from red, green, and violet by combining two of them or the three in certain proportions, whereas these three colours cannot be produced by mixing others. For this reason they are called primaries and the other spectrum colours are called secondaries. Thus red and green, in varying proportions, produce orange and yellow, while green and violet produce blue and indigo. Red and violet produce purple, which, however, is not in the spectrum. Colours not found in the spectrum result from the mixture of non-adjacent wave-lengths.

Complementary Colours.—All the spectrum colours are not required to produce white light; it suffices if any two which are complementary to each other are combined. Hence a complementary colour may be defined as that which, when united with another, produces white light. The complement of a primary colour is that secondary colour which results from the mixture of the other two primaries. The complement of a secondary colour is mainly that primary colour which is not contained in it. Thus white light always contains certain proportions of the three primary colours. Visually one can learn the complement of any colour by producing a negative after-image.

SPECTRUM COLOURS AND THEIR COMPLEMENTS

Spectrum Colour.	Complement.
Red.	Green-blue.
Orange.	Blue.
Yellow.	Blue-violet.
Green.	Purple-red.
Blue.	Orange.
Indigo.	Orange-yellow.
Violet.	Green-yellow.

Brightness of Colours.—In a prismatic spectrum the red appears brighter than the violet because the former is more crowded together, while the latter is spread out. This is not the case, to the same degree, in a diffraction spectrum, where the centre colour is yellow, the remainder of the spectrum being of about equal length on each side. The brightest part of the spectrum to the human eye is the yellow, and, in general, the intensity rises rapidly from zero, at the extreme red, to the yellow, and then, dropping off again, but more slowly, to zero at the extreme violet.

Colours of Bodies.—A substance is said to be of certain colour when it reflects or transmits rays of certain wave-lengths and absorbs the rest of the spectrum. Thus an object which absorbs the violet and green and reflects the red waves appears red. If it absorbs red waves and reflects green and violet, it appears blue. A green body absorbs all but the green waves, and one orange in colour reflects red and green but absorbs violet. The colour reflected by a body is usually the same as that which it transmits, but some bodies—termed dichroic—transmit the complementary colour to that which they reflect, or a different colour; thus a thin sheet of gold reflects deep yellow and transmits green.

The colour of a body depends on its thickness, and there is a marked variation with thickness in the colour of some transparent or semi-transparent substances. Thus *crème de menthe* appears by transmitted light green, yellow, and red as it is respectively thin, medium, or thick. Permanganate of potash, which is a deep purple, almost black, as a dry substance, becomes in solution red, purple, or dark-blue according to strength. A piece of smoked glass which if thin appears greenish by transmitted light, may transmit a brilliant red if it is thicker. A certain depth is needed for absorption of colour to occur; thus the froth of water and powdered ice are pure white, as are many other coloured bodies when powdered.

Dark colours reflect little light, and slight differences between them are hardly appreciated in dull illumination; similarly, light colours reflect much light, and slight differences are hardly noticed in very bright illumination. All colours lose their distinctive hue in proportion as the light reflected becomes reduced. Thus with dull illumination all colours appear dark grey.

A body reflecting light of all wave-lengths is called white; a body having affinity for all colours, so that all are absorbed and none reflected, is called black. No body, however, is of a substance so chemically pure as to absorb entirely or reflect all the incident light. An absolutely black body does not exist in nature; even those coated with lamp-black and soot reflect some light, which renders them visible and allows of their form, under certain conditions (see Light Control and Shadows, p. 27), and solidity being recognized. Similarly, there is no object which reflects all the light it receives; pure, fresh snow, which is the whitest of all bodies, absorbs some 30 per cent. of the light it receives.

Colour is a quality of the illuminating light itself, as well as of the body which reflects it. In order to appear of a certain colour, the object must receive that colour in the light and reflect it, at the same time absorbing all the other colours.

White, grey, and black are really varying degrees of brightness, the only difference between them being in the total amount of light reflected. In all three the absorption is the same for all colours, *i.e.* there is no selective power as with coloured bodies, but the extent of the absorption varies in the three cases.

Colours in Pigments.—The primary colours in pigments (paints or colouring matter) are red, yellow, and blue; any other colour is obtained by mixing the primaries. The actual tints of the primaries are not those usually associated with their names, except in the case of the yellow, which is fairly pure; the primary blue tends towards green, and the red towards purple, and these would be better described as peacock-blue and rose-red respectively.

The primaries and their complements are shown in Fig. 10, from which it will be seen that the primaries of pigments are the complements of the primaries of light. Thus 1, 6, and 10 are the primaries of light, and 4, 7, and 12 are the primaries of pigments.

The Mixing of Colours.—The fundamental difference in the results obtained by mixing spectrum lights and pigment colours lies in the fact that the former is an additive and the latter a subtractive process. In other words, the coloration of mingled lights is due to the sum of the separate wave-lengths, while the resultant colour given off by the mixture of pigments is that remaining after each pigment has absorbed a certain wave-length or series of wave-lengths. The tendency of added lights is to give increased illumination and to approximate to white, while with pigments a mixture tends towards black. Thus, when the primaries of light, *i.e.* red, green, and blue-violet, are mingled—projected, say, from three separate lanterns—the white screen reflects all three impartially to the retina, where their superposition produces the sensation of white. With pigment, however, the final colour is due to that remaining after each pigment, in a certain mixture, has absorbed from the incident white light its own complement.

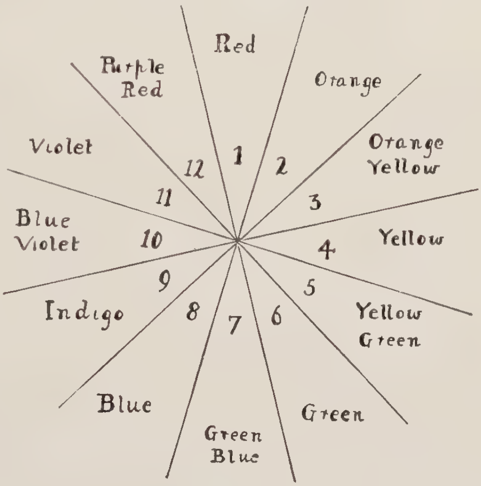

Fig. 10.

In this way the primary colours of pigments are those capable of absorbing the three primaries of white light, *i.e.* red, green, and blue-violet, whose respective complements are green-blue (peacock-blue), purple-red, and yellow. These last three are therefore the primaries of pigments, because, when mixed in the right proportion, they (theoretically) produce black. In practice, however, owing to the inevitable impurities of pigments and the impossibility of securing the correct proportions, the result is a dark grey. For the same reason it is impossible accurately to match the spectrum colours by means of pigments, and this is especially the case towards the violet end. In fact, we cannot imitate spectrum violet by any known pigment or combination of pigment colours.

In some instances the effect of a pigment mixture may be surprisingly different from the result of mingling lights of corresponding colours. Thus blue and yellow pigments combined make green. From an additive aspect the blue reflects violet and green, the yellow reflects red and green; if the two be mixed, there is reflected a certain quantity of violet and red and a double quantity of green, so that the residual green gives the colour to the mixture of the two pigments; or, from a subtractive aspect, the blue absorbs red, the yellow absorbs violet, so that only the green remains to be reflected. If, however, blue and yellow lights are mingled in the right proportion on a white screen, they cause the sensation of white. Red and blue-green are complementary colours which, added to one another, produce white in the case of coloured lights (additive effect), but neutralize each other, *i.e.* produce (theoretical) black, in the case of pigments (subtractive effect). If red and yellow lights are mixed, they cause the colour sensation of orange; if pigments of these colours be mixed, they also reflect orange, since both absorb practically the same wave-length.

The additive effect in the case of light can be roughly imitated by painting yellow and blue sectors alternately on a disc, which, when rapidly rotated, gives the impression of white if the proportions of colour are correct. Here the yellow and the blue alternate so rapidly on the retina that the sensations caused by alternate sectors are mingled and give rise to the sensation of white. The experiment must, however, be carried out in white light; but even then the effect is generally far from pure, owing to the muddiness of the pigments, and, in fact, it is so dirty a white that it might more properly be termed grey.

Newton, from experiment, gave the best sizes of the sectors of a disc, consisting of reproductions of the seven principal spectrum colours, to produce the sensation of white. The values are approximately as follows:—

Red, 60°	Orange, 35°	Green, 60°	Blue, 55°	Violet, 60°
	Yellow, 55°		Indigo, 35°	

By increasing the number of sectors, and repeating the seven spectrum colours in the above proportions all round the disc, a still better white is secured.

Qualities of Colours.—Colours in pigments possess three qualities, viz. tone, brightness, and purity. Tone, or hue, is that quality which differentiates between the various colours—say red and orange; it depends on the wave-length. Brightness, intensity, or luminosity is that quality which represents the strength of a colour and depends on the amount of light reflected; one which reflects little light is a dark colour, and one which reflects much light is a light colour. Fulness, saturation, tint, or purity is that quality which represents the depth of a colour; the less the admixture of white or black, the purer is the colour. Red mixed with white forms pink, whereas red mixed with black makes a kind of maroon; yellow and orange become straw and brown according as they are mixed respectively with white and black. Thus we say that yellow or orange is a pure colour, while straw and brown are impure.

Coloured Bodies and Lights.—The real colour of a body is that which it exhibits in white sunlight; when seen by artificial light it will generally be appreciated as of the same colour, provided the luminant radiates all the spectrum colours. It does, however, appear of a different tone, or intensity, or tint, due to the fact that some particular colour usually predominates in artificial light, and therefore the mental standard of white is temporarily shifted towards that colour. Thus ordinary gaslight—not incandescent—contains an excess of red and yellow, while blue and violet are the prevailing colours in the electric arc. The nearer the colour of a body approaches to that of the illuminant, the whiter will it—the body—appear; on the other hand, should the colour of the body be nearly complementary to that of the illuminant, it will appear darker than it would if viewed in white light. Should the light be of a colour exactly corresponding to that which the body absorbs, none will be reflected and the body will consequently appear black. Of course, a white body seen by coloured light is really coloured, although it is generally interpreted mentally as white, and it certainly is so accepted if the coloration of the luminant be not excessive.

Thus, for instance, green is seen as green in a light which is white or which contains all the spectrum colours, but it will be modified if any one colour predominates in the light; it will appear white if the light is green, or if green largely predominates, and it will be black in a pure red light. If a coloured body be viewed by the one eye by daylight, and by the other by artificial light, its colour is markedly different to the two eyes. Again, these differences vary as the eyes were previously adapted for daylight or for the artificial light. Painting and matching colours are always difficult in artificial light, and some blues and greens can barely be distinguished by gaslight, and still less by lamp- or candle-light.

Coloured Bodies and Glasses.—The conditions are very similar to those considered in the last section.

All colours are profoundly modified when viewed through coloured glass, as the reader can prove for himself. If the coloured glass absorbs the rays reflected by the body, the latter appears black; it appears white, or at least indistinguishable from white, if the glass is of the same colour. Here the colour of the glass is temporarily the mental standard of white. Thus red letters on a black ground, viewed through a green glass of the proper shade, become invisible, the red rays reflected or transmitted by the letters not traversing the glass. Red letters on a white ground, seen through a red glass of proper shade, similarly become invisible, the whole being of uniform tint. On looking at a green object on a red ground through a piece of green glass, one sees an apparently white object on a black ground.

Thus there is the curious circumstance that a colour can be made invisible by the use of a glass of its own colour or by one of its complementary colour. In the first case the invisibility results from relative brightness, and in the second from relative darkness of that colour, or, put in another way, by saturation and exclusion respectively.

Shadows.—A shadow is cast by a body when it intercepts the light from a source, so that a dark space may be seen on the wall or ground where the shadow is. The latter, resulting from the interception of white light, appears grey or black, because less light or none at all is reflected from that area of the wall or ground occupied—if one may use the term—by the shadow.

The shadow resulting from the interception of a coloured light appears to be of the colour complementary to that of the light. This occurs because the illumination of the ground is coloured and the light reflected from it is mentally taken as the zero of the scale of colour sensation, and the darkened space, *i.e.* the shadow, then appears complementary to that light. If two shadows are cast—the one by a red and the other by a white light—the shadow resulting from the red light appears greenish as the result of contact with the reddish ground, and with the other shadow, which is tinged with red since it receives only that coloured light. (See Light Control and Shadows, p. 27.)

Superposition of Coloured Glasses.—When two coloured glasses are placed together we have an example of the subtractive process similar to that seen in the mixture of pigments. The first glass eliminates from incident white light all but its own colour, and, if the second glass is the same as the first, no further alteration takes place except a slight reduction in intensity due to absorption. If the second glass is not of the same colour as the first, a certain amount of absorption by subtraction takes place in the second; and the more nearly complementary the two glasses are, the more nearly will the whole of the incident light be cut off. For example, if a blue-green and a red, or an orange and a blue glass, be placed together, the light transmitted by the one is absorbed by the other and the combination rendered opaque. Cobalt glass transmits red and blue, ordinary green glass transmits blue and green; on the two being placed together, original white light transmitted appears blue, since the blue is transmitted by both but the remaining colours are absorbed.

Sensitivity of the Eye to Different Colours.—Green, which prevails in nature, fatigues the eye least of all the colours; then blue-grey, purple, yellow, orange, and red, the last being the most fatiguing. For this reason, billiard-tables are covered with green cloth, and blinds are frequently of that colour. The sea and sky are blue, red and orange occurring only in patches or occasionally, as at sunset; the eye is able to bear those colours best which are most widely distributed in nature, and most likely in consequence of this. The human eye is most sensitive to yellow, whether seen in the spectrum or by reflected light. A clear distinction must, however, be drawn between seeing a coloured body and distinguishing its characteristic colour, whether with respect to distance or feeble illumination. If the colours are equally intense, yellow and red can be seen farther than others. Generally, as a characteristic and recognized colour, red is the most persistent of all ; owing to its long wave-lengths it freely penetrates haze, fog, or smoked glass, while the penetration of other colours follows more or less in the order of the spectrum. For this reason, red is employed as the danger signal, while blue-green is employed as the contrast signal, on railways and ships. The sun appears redder at sunrise and sunset than at midday, and also in fog, the blue-violet end of the spectrum being absorbed by the atmosphere.

In a feeble light all colours lose their distinctive coloration ; and while blue, as a colour, would disappear before red, a blue body would be visible when a red one was no longer so, as mentioned in the next article. Yellow, the first to disappear as a colour, is the last to remain visible in a dull light.

Purkinje's Experiment.—The greater the power of a source, as measured by a photometer, no matter what its colour may be, the more nearly does it approximate to white. Conversely, as the intensity is lowered, all colours approximate to black, but the approximation is not the same for all. Thus the sun viewed through glass of any colour appears whitish ; while if its image be projected by means of a convex lens through any coloured glass, the focus will also appear nearly white, provided the density of the glass be not excessive. Purkinje, in experimenting with feeble illumination, discovered that vision for the shorter waves was more persistent than for the longer ones. If two parts of the spectrum, say red and blue, be taken and rendered equally intense, the red will appear to most people as being the brighter ; but as the illumination is lowered the red fades more rapidly than the blue, so that, when the red has altogether disappeared, the blue is still visible as pale grey. Similar phenomena may be noted with coloured bodies ; *e.g.* when red and blue paper are viewed in light sufficiently feeble to render the red black, the blue will still be visible as greyish.

Sensitivity to Intensity.—Although the eye is well adapted for distinguishing between the tints of two bodies, it is very defective in detecting the difference in intensity between two differently coloured sources. With practice we can observe a difference in the hue between two colours having only a small difference in wave-length, but we generally fail to get within even an approximate estimate of their relative intensities. According to Fechner, the eye is capable of detecting a difference of 1 per cent. in two adjacent white surfaces of average illumination ; but with colours an estimate of such accuracy is quite impossible, and the difficulty increases as the colours chosen are opposite in nature, *i.e.* complementary. Thus if a red and a green source be taken, their difference in colour is most apparent, except to a colour-blind person, but practically every one would make large errors as to their relative intensities. It is, however, possible to balance photometrically the intensities of any two coloured sources; but even then another difficulty arises, and that is the change in sensitivity of the eye to the various hues as their intensity is uniformly varied. This phenomenon was first discovered by Purkinje, and afterwards elaborated by others.

Colour Fatigue and After-Images.—If the retina be subjected to prolonged exposure to light of a certain colour we have the condition known as retinal fatigue, the immediate effect of which is to cause temporary blindness for that particular colour. Some little time elapses before the retina recovers its normal sensitivity, but recovery is generally hastened by blinking and moving the eyes about. This phenomenon may be easily demonstrated in various ways. Thus if we stare intently for a few minutes at a row of letters coloured alternately red and green and then suddenly transfer our gaze to a white or grey surface such as a ceiling, the outlines of the letters will be seen, but in complementary colours, those that were originally green appearing red, and *vice versa*. Or we may take as an object a blue-paper cross on a yellow background, the after-image of which appears as a yellow cross on a blue ground, and so on. The after-image of a white cross on a black ground would be a dark cross on a light ground.

The nerves, on saturation by a colour, are apparently rendered abnormally sensitive to its complement, but actually this is due to their inability to respond to the original colour after prolonged exposure. By means of a coloured glass we can, when it is removed, thus render the eye temporarily blind for that particular colour; but with the glass kept in position, the colour to which the eye is artificially blind is complementary to that of the glass.

The Mental Standard of White.—Saturation of the retina by any colour causes the standard to be displaced; the mind accepts that colour as the zero, just as white is considered to be the zero in ordinary circumstances. Thus if on a coloured sheet a very small piece of white be placed, the latter appears of the complementary colour to that of the other. If the sheet be red, this presently appears more nearly white, and the white then appears bluish-green. It would appear that one mentally conceives as white that body which reflects most light, and, generally, that a white body is white whether seen by sunlight or coloured artificial light, although actually the appearance would be quite different if a comparison were possible. We do not, in reddish gaslight, take white to be other than white, for our colour standard is then altered for the coloured light. It is for this reason that a red body on a white ground, seen through a red glass, is indistinguishable from the ground, since they both appear the same whitish colour.

Perception of Black.—A black object is seen because a retinal image is formed of the surroundings, *i.e.* the mind appreciates the gap in the visual field. Nevertheless, a black body does radiate some light, and most likely it is appreciated as an intensely dark grey, *i.e.* a combination of black and white elements, for the difference between grey and black is merely one of degree. Therefore black may be considered a colour in a certain sense, for if an object reflected no light at all it would be invisible, whereas a so-called black body is mentally appreciated. Thus a solid body, black in a popular sense, is seen, not as a flat gap in the visual field, but as a body having three dimensions. According to Hering, black causes a distinct sensation, the complement of, or opposing sensation to, white.

The seeing of a black body is entirely different from the visual sensation one experiences in a totally dark room, and this is quite different from that of an image projected on the blind spot of the eye. In the former case one undoubtedly perceives the darkness; in the latter case one does not perceive anything, and therefore one is unconscious of the gap in the visual field. We must therefore distinguish between the absence of all light stimulation on a portion of the normally active retina, capable of conveying a colour sensation to the brain, and absence of the capacity so to convey it; also between partial and total absence of light.

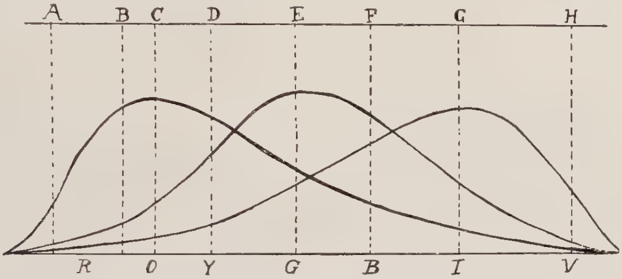

FIG. 11.—DIAGRAM ILLUSTRATING THE YOUNG-HELMHOLTZ THEORY OF COLOUR VISION.

The letters refer to Fraunhofer's lines; the height of the curve corresponds to the intensity, and the length shows the part of the spectrum covered.

Colour Vision.—The usually accepted interpretation of colour vision is that known as the Young-Helmholtz theory. According to this theory, the retina possesses three sets of elements, each one responsive to the stimulation of one of the three primary colours, viz. red, green, and violet. It is supposed that red light stimulates mainly the red retinal elements, but also to a less extent the green, and, to a still less extent, the violet. Similarly, the violet retinal elements are mainly stimulated by violet light, but this also slightly stimulates the green and red retinal elements. In the same way the green elements are chiefly, and the red and violet elements slightly, excited by green light.

Stimulation of one of the three elements produces the sensation of a primary colour; stimulation of two causes a sensation of a secondary colour; equal stimulation of the three elements causes the mental appreciation of white; stimulation of the three to varying extents causes the sensation of the predominant colour diluted with white.

Yellow, which is the brightest part of the spectrum, and the wave-length on which clear vision mainly depends, is, according to this theory, a compound sensation, as is also spectrum blue, colours which in the spectrum have definite wave-lengths even if they are also capable of having their sensations produced by mixture of other colours. Indeed, it is difficult to conceive that the retina consists wholly of red, green, and violet elements, for if so a person blind for one colour should have a reduced visual acuity in consequence; one totally colour-blind should be also totally light- and form-blind, but neither of these is the case.

It is possible that some of the retinal elements are stimulated by all light equally, while others have a selective faculty, each being sensitive to a given wave-length only. Or it may be that the faculty of discriminating between the effects of waves of different length or frequency lies in the brain, there being different centres for colour, light, and form.

Hering's theory of colour vision is based on the supposition that there are three pairs of sensations, viz. black and white, red and green, blue and yellow. The sensation of white results from decomposition of the black-white substance, while darkness results from its regeneration. Red or green results from decomposition and regeneration of the red-green substance, and similarly blue and yellow from those of the blue-yellow substance. Various other theories of colour vision have also been advanced.

The history of man would seem to indicate that the colour sense is, or has been, progressive. The colours mentioned by ancient writers are few in number, so that it may be conceived that the perception of different colours, and shades of colour, has increased with the development of painting and the fine arts. Even to-day a person possessing the most normal colour vision cannot differentiate between closely adjacent portions of the spectrum, and one has to view fairly distant portions in order to be able to appreciate a real difference of tint. Nevertheless, among dyers and milliners the sense of colour is highly developed; by training they can distinguish fine differences of shade and hue in ribbons and dress materials which to one untrained appear more or less the same in colour.

A knowledge of colour and of the application of coloured light is an essential of illuminating engineering. In the shop window, the home, the hotel—in fact, wherever artificial light is used—the judicious use of colour cannot fail to charm, since we are all susceptible to a colour sense.

Light Control and Shadows

All objects are seen by the nature of the light which is reflected from them; it is therefore true that light is the physical cause of sight, or what may be more correctly termed the *sensation* of sight. All bodies which in themselves are capable of creating this sensation are termed self-luminous bodies; some non-luminous bodies become luminous when in the presence of a luminous body.

Light from a source must pass through space before it illuminates an object; this space is termed a medium. All media which assist in the transmission of light, although in all media a certain amount of light is absorbed, are termed transparent media; the degree of transparency, however, depends upon the nature of the medium. Clear glass and opal glass are good examples of transparent media although they are transparent to a different degree. Such media, since they are uniform throughout in structure and properties, are known as homogeneous media. Bodies which do not transmit light at all are known as opaque bodies, so that transparent media—such as the ether, glass, etc.—and a black body (opaque) may be said to represent the extremes in light transmission.

It is certain that in transmission from any light source to an object the light rays lose some of their original properties; the extent of this alteration or loss depends upon the nature of the media through which the rays pass. When considering light from a directional point of view it is necessary to look upon the rays as travelling along particular lines or to and from a particular point. In other words, it may be considered that a number of adjacent rays diverge from, or converge to, a point, or they may run parallel with each other (see Fig. 12). Light rays from the sun are actually divergent, but owing to the enormous distance of the sun from the earth they may be considered as parallel rays. In Fig. 12 the axis of the cone AB is the central ray, and the point A, from which the rays diverge and to which they converge, is known as the focus.

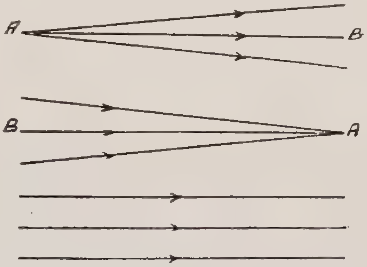

Fig. 12.—Divergent, Convergent, and Parallel Light Rays.

A ray of light travels in a straight line through the same medium; in an artificial-light source the rays are divergent, but in the same medium they travel in straight lines. A bare-light source L is illustrated in Fig. 13. It will be seen that the rays are divergent, and that a considerable proportion are in an upward direction. Light control is to collect the upward rays and redirect them in any desired direction where they can be profitably utilized.

The fundamental principles of light control may be demonstrated by means of a stereopticon lantern; the design of the lantern is such that a concentrated beam of light is produced in which various types of reflecting and transmitting materials are placed, thereby showing how various substances affect the light which falls upon them.

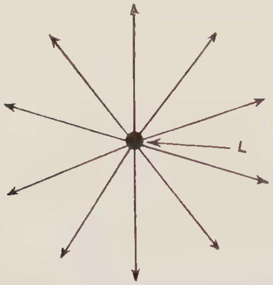

Fig. 13.

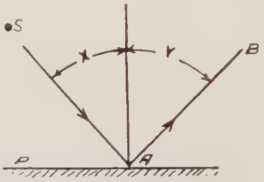

Fig. 14.

When a ray or a number of rays of light encounter an object, the direction of the rays is altered; this is illustrated in Fig. 14, where S is a light source and P is a polished metal surface. The light ray emanates from S and, striking the surface at A, is reflected in the direction AB. The angle Y, known as the angle of reflection, is equal to the angle X, termed the angle of incidence.

This is shown by the simple experiment illustrated in Fig. 15, where a frame F is fitted with two tubes which are free to move round the frame; in the centre, with its face on the base line, is a mirror M. A ray of light passing through the tube will strike M at a certain angle. If the other tube is moved so that the reflected ray can be seen with the eye, it will be found that the distance X from the vertical is equal to the distance Y from the vertical. This reflection is known as regular reflection or specular reflection.

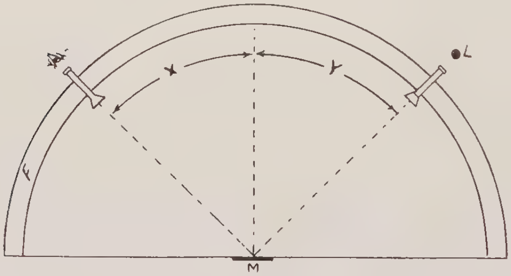

Fig. 15.

If the light source and the tube are moved, the ray will be reflected at a different angle, a fact which goes far to teach us that light can be perfectly controlled after due consideration has been given to the nature and direction of light sources and reflecting media.

Light rays behave differently with various kinds of reflecting media. It is well known that an ordinary glass mirror is composed of clear or crystal glass with a backing of silver. When a ray of light strikes such a mirror, two rays are reflected from it, as illustrated in Fig. 16. The light rays are indicated by the arrows, and it will be seen that, of the two reflected rays, one is reflected from the surface of the glass and the other from the silver on the back of the glass. Since the surfaces of glass and silver are parallel to each other, the reflected rays will also be parallel. The nature of the single ray is altered owing to the fact that, after reflection, it is 'split.'

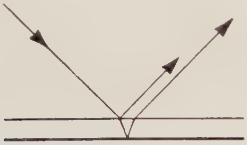

Fig. 16.

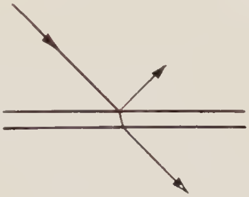

Fig. 16*a*.

In the case of a piece of clear glass, when a ray strikes its surface part of the ray is reflected and part passes through the glass, as illustrated in Fig. 16*a*. It should be noted that in passing through the glass medium the direction of the ray is altered, but upon leaving the glass its direction is parallel to its original direction; this, in effect, is equivalent to 'bending' the ray.

The action of a glass prism on a ray of light is more peculiar. It has already been shown how a light ray is bent out of its normal path when passing through a flat piece of glass; in a prism the direction of a light ray is changed more or less sharply according to the angle at which the first ray strikes its surface. When a certain angle is reached, the direction of the ray will be actually opposite to that of the first ray, or 'bent back upon itself,' as illustrated in Fig. 17. This principle of light direction is taken advantage of in the design of prismatic-glass reflectors.

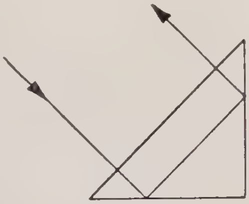

Fig. 17.

Another feature is manifested in a true glass prism; this is that from a narrow beam of light a spectral band is formed. The reason for this is that the various colours of the spectrum which go to make white light, having different wave-lengths, are deflected at different angles; the result is that one observes a band of beautiful colours with red at one end and blue-violet at the other.

All light which contains these colours in more or less quantities may be termed white light, although, actually, the only real white light is solar light, light which emanates from the sun. Newton was the first to show that light from the sun was of a composite character; he often demonstrated this in a dark room with a ray, or beam, of sunlight, and a prism. The demonstration is so interesting that it will not be space wasted to explain it.

In Fig. 18 are illustrated two sides of a dark room. A beam of sunlight is allowed to enter the room through the hole H; such a beam is divergent, and forms a pencil of light between H and R. The characteristic of this beam is that it forms a bright elliptical spot on the wall at R. A prism P was then placed in the beam with its edge downwards, as shown; it was then found that the pencil was deviated from R and deflected or refracted upwards to R¹ and R². Not only was the beam refracted, but the vertical diameter was much larger, and, instead of a bright elliptical spot, a number of coloured bands could be seen in the horizontal plane.

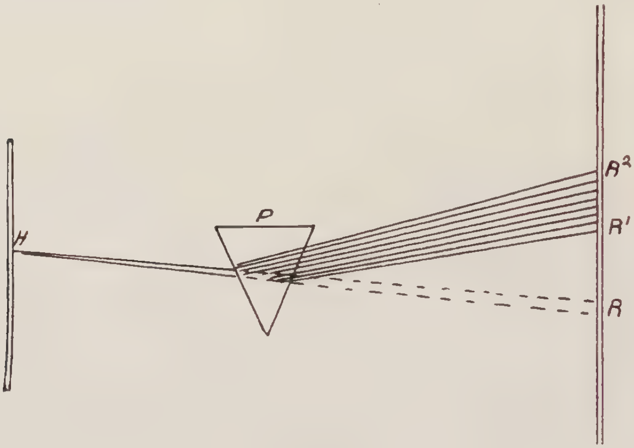

FIG. 18.

The bands thus seen are the normal spectral bands, and in colour are red, orange, yellow, green, blue, indigo, and violet. In refraction the red is deviated the least, so that its position on the wall is at R¹; the other colours follow in the order named, so that the violet band is on top. This spectrum is known as the visible spectrum, but from all light sources below the red are a number of invisible rays known as the dark heat rays; these do not create the sensation of sight. The remainder of the colours in the spectrum excite the optic nerve and result in the sensation of sight. Throughout the whole range of the spectrum, however, the intensity of light has different values. The maximum intensity is at the yellow, as illustrated in Fig, 19, but, of the whole spectrum, the intensities of orange, yellow, and green are the most pronounced.

The end of the violet band is the end of the visible spectrum, but at this end other rays exist which cannot be seen; these are known as the dark chemical rays, or actinic rays. These rays are extensive, and it is doubtful if their magnitude has ever been determined.

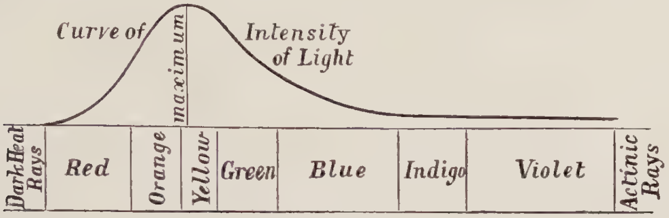

FIG. 19.

Since white light consists of a combination of colours, a beam of white is said to be composed of rays of different frequencies. The velocity of light is the same for all frequencies, from which it follows that waves of a high frequency have a shorter wave-length than low-frequency waves; the waves may be compared with sine waves, so that they have definite values from zero to zero or from crest to crest. The relative values of red, green, and blue are illustrated in Fig. 20. The respective wave-lengths are measurable, and the unit of measurement is the Ångström unit (ten-millionths of millimetres); the lengths of the waves in the visible spectrum in Ångström units are illustrated in Fig. 21.

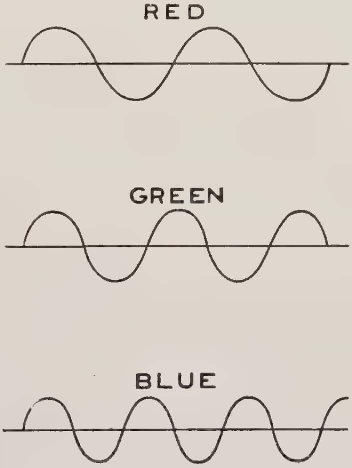

FIG. 20.

Referring again to an ordinary glass mirror, if this is broken and the pieces are allowed to rest on a board or table in various planes and light is projected upon them, the direction of the rays of reflected light will be at various angles, as illustrated in Fig. 22. On the other hand, if a piece of smooth glass is coated with aluminium paint and rays of light are projected upon it, light will be reflected in directions differing but slightly in their angles. This is because, although the surface of the glass is smooth, the paint presents a kind of matte surface which may be likened to a number of small mirrors; the latter are so minute that their beams merge into each other and form a spot of light or luminous body, the edge of which fades away, so that there is no harsh contrast.

This type of reflection is known as spread reflection; and it is adopted on a large scale in the design of floodlighting projectors where a fairly concentrated beam is required, but where it is most essential that a sharp cut-off on the edge of the beam should be avoided.

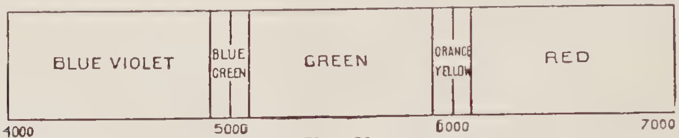

Fig. 21.

When a light ray strikes a piece of porcelain enamel or glazed paper it is reflected as from a plane mirror. The whole of the ray is not so reflected, as will be seen from Table I, which shows that, in the specular reflection of a beam striking a porcelain enamel surface, from 5 to 10 per cent. only is so reflected, and in the case of glazed paper only 3 to 5 per cent. The remainder of the light is reflected at various angles, the major portion travelling in directions which lie inside the cone generated by the revolution of the incident ray about the normal (see Fig. 23).

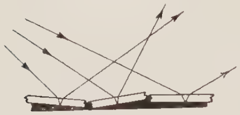

Fig. 22.

Blotting-paper, or any paper with a rough matte surface, acts in a similar manner to a surface covered with a large number of tiny mirrors not in one plane, so that light is reflected in all directions; such a surface is illustrated in Fig. 24, from which it will be seen that the greater portion of the light is reflected in an upward and almost perpendicular direction to the surface. White plaster and similar materials act in a similar manner. For this reason such surfaces are desirable for rooms in which well-diffused illumination is desired. The reflection factors of various substances are indicated in Table I.

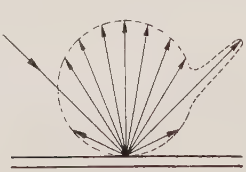

Fig. 23.

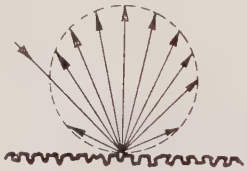

Fig. 24.

In the control of light there are many substances used to transmit light rather than to reflect it; Table I gives the difference in the properties of reflection, transmission, and absorption for various kinds of glass. Clear glass, it will be seen, transmits the greater portion of the light which falls upon it. This is not the case with sprayed lamps, as will be seen from Fig. 25; this illustrates a section of the bottom portion of a white-sprayed lamp; the thickness of the glass is exaggerated to show the action of a light ray from a point L of the filament.

The ray strikes the inside of the bulb at A, and passes through the glass at a different angle; here it strikes C, the material with which the lamp is sprayed. The small white particles of matter of which the material is composed present a large number of reflecting surfaces to the ray, with the result that a number of rays emanate from C in all directions. At the same time the reflection of the ray from the inside of the bulb along AB forms another source for diffusion when it encounters the material; the intensity of the second ray, however, is much lower. The same effect is obtained from a piece of opal glass, as illustrated in Fig. 26.

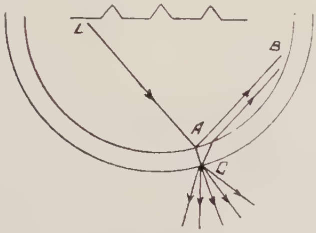

Fig. 25.

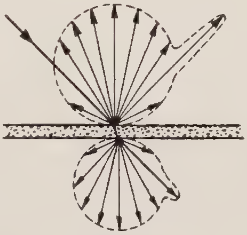

Fig. 26.

From this it is apparent that light from clear and sprayed lamps will produce different effects. We have carried out experiments to determine the nature of these effects, especially with regard to the production and elimination of shadows.

In our first experiment we used a small piece of wood 2 inches square and 8 inches long; on the top of this piece was secured a thin piece of wood, thus forming one piece. The wood was painted dead black and placed upon a white sheet. In a darkened room a clear gas-filled lamp was placed on the left side of the wood, but slightly above it, at a distance of about 3 feet; when the lamp was lit the effect was photographed, and is illustrated in Fig. 27. A shadow is seen on the sheet to the right of the object; the centre of the shadow is very dense, but towards the edge it is much lighter.

Another clear lamp of the same candle-power was then hung in a similar position on the right of the object; the effect is indicated in Fig. 28. Here two shadows are seen, one on each side of the object; it should be noted that the shadows are not so dense, and that lighter shadows fringe the denser one. The clear lamps were then removed and white-sprayed lamps were placed in the holders; the effect is illustrated in Fig. 29. Here it will be seen that the shadows have entirely disappeared.

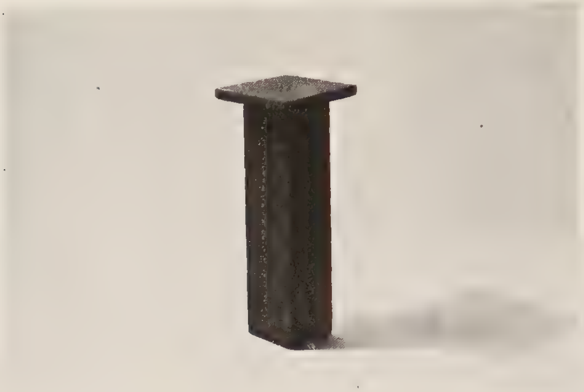

Fig. 27.

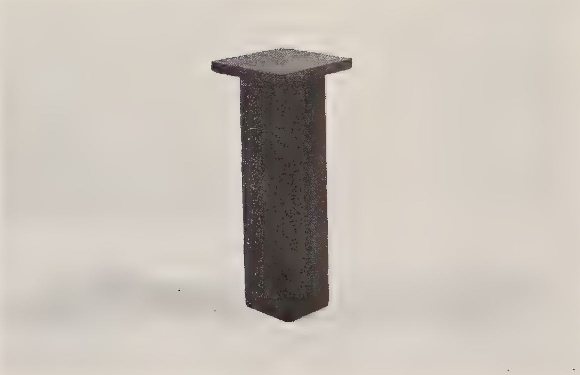

Fig. 28.

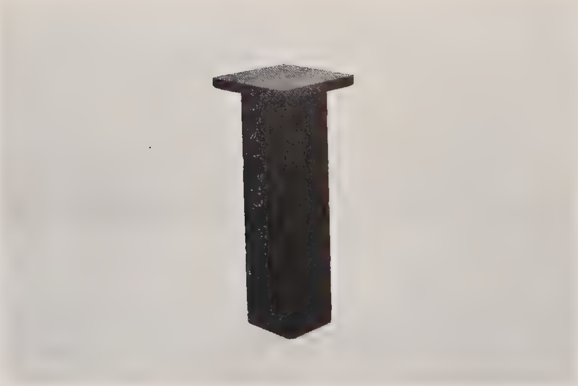

Fig. 29.

If the results of these tests are not correctly interpreted it is possible that wrong impressions may be created. We know that in good lighting harsh shadows should be eliminated, and in our experiments white-sprayed lamps had the effect of removing the shadows cast by the object. It must not be taken for granted, however, that because the shadows are removed the principles of good lighting have been applied. Good lighting means the elimination of shadows, but with this elimination it must be possible to see an object clearly and to determine its shape.

If we again consider Fig. 27 it will be seen that although the object shows a dense shadow its shape can be clearly seen. Compare this with the illustration of the object with the shadows removed, and it will be seen that the shape of the object in the centre cannot be determined. If a piece of paper is placed over the top and bottom of the illustration it cannot be seen whether the object is round or square; with the paper removed the shape is apparent only by the corner at the bottom.

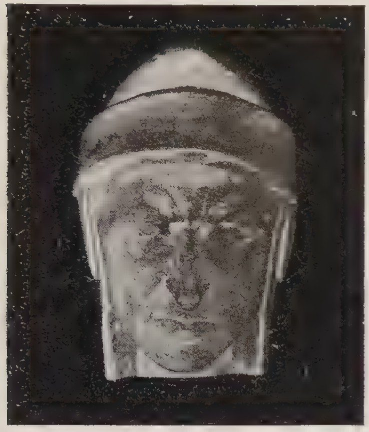

Fig. 30.

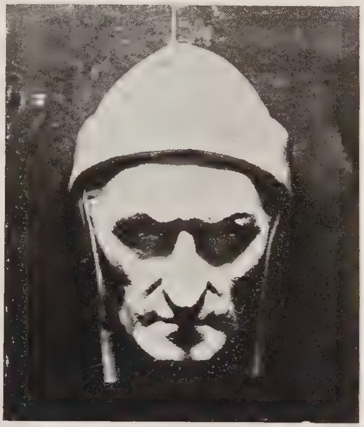

Fig. 31.

Further proof that if light is too well diffused the shape of objects is lost, is illustrated in Figs. 30 and 31. These illustrations are of a plaster-cast of a face in a box, viewed under two different arrangements of light. In the first illustration the light is well diffused; the effect is that the face is quite expressionless. In the second illustration the light is directional, from the top of the box; the effect is that shape is given to the eyes, nose, mouth, etc., and the side drapery takes on shape.

This kind of lighting would appear to be ideal, but further experiments proved that if directional lighting is too strong the identity of

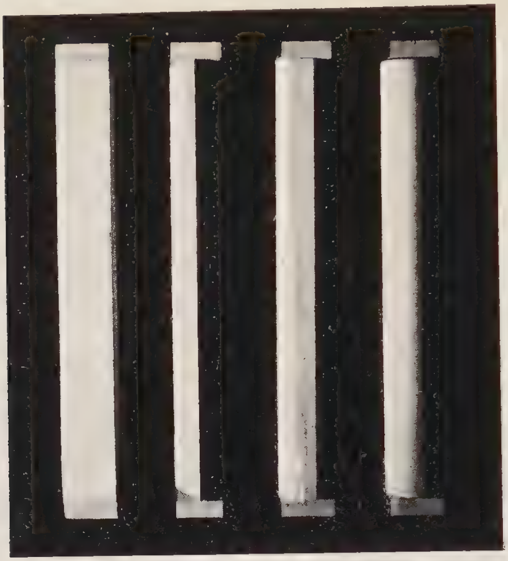

Fig. 32.

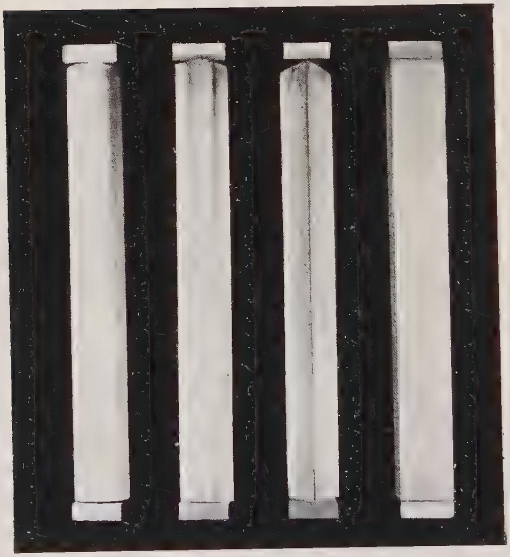

Fig. 33.

objects is also lost. This is illustrated in Figs. 32 and 33, where a number of sticks of different shapes are shown in a box under different degrees of directional light. In one case the shadows are so dense that parts of the objects are obliterated; in the other case the shadows are of exactly the right depth to reveal the objects without harsh contrasts.

The production of shadows of the right quality is an essential of sound illuminating engineering. A bare-light source must produce shadows by virtue of the fact that, relative to an object, it is a luminous point. This is illustrated in Fig. 34, where L is a bare-light source, B is an object, and S is the resultant shadow ; the latter is the result of the interception of light rays by B. If L be a luminous body, as shown in Fig. 35, a cone of shadow is produced, but it has two densities, the umbra and penumbra. The umbra is the central shadow, and the penumbra is the partial or outer shadow. The luminous body is visible from any part of the penumbra, but the density of the latter is not the same over its entire area. Towards the fringe the shadow is very light, but as the outer boundary of the umbral cone is reached it becomes more dense.

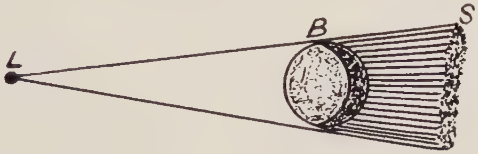

Fig. 34.

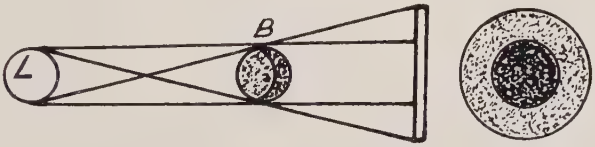

Fig. 35.

A reflector in a shop-window installation is a luminous body ; the same may be said of a dispersive-type reflector in an industrial interior. The correct application of light is the provision of equipment which will produce directional and diffused illumination in such quantities as to provide just the right grade of shadow for each particular purpose.

TABLE I

REFLECTING AND TRANSMITTING MEDIA AND THEIR CHARACTERISTICS

	Direct or Specular Reflection. Beam at 45 degrees	Total Reflection
1. Polished metal	55–60%	55–60%
2. Plain glass mirror	80–85%	80–85%
3. Aluminium paint	...	60–65%
4. Porcelain enamel	5–10%	65–70%
5. Glossy paper	3–5%	80–85%
6. Blotting-paper	...	80–85%
7. Magnesium carbonate	...	96–99%

Transmitting Media	Reflection	Transmission	Absorption
8. Clear glass	10–15%	80–85%	5%
9. Frosted glass, smooth side	15–20%	70–80%	5–10%
Frosted glass, rough side	17–22%	65–75%	5–10%
10. Pebbled glass	15–20%	70–80%	5–10%
11. Ribbed glass	10–15%	70–80%	10–15%
12. Prism glass	10–15%	70–80%	10–15%
13. White glass	20–60%	20–60%	10–30%
14. Rippled glass with opal	20–25%	60–70%	10–15%
15. Red screen	...	15–20%	...
16. Green screen	...	10–15%	...
17. Blue screen	...	2–10%	...
18. Amber screen	...	25–30%	...

CHAPTER III

INDUSTRIAL LIGHTING

Lighting Designs—Types of Reflectors—General Considerations—Polar Curves of Controlled and Uncontrolled Light—Effect of Incorrect Spacing—Calculations—Watts per Square Foot Method of Calculation—Lumen Method of Calculation—B.E.S.A. Specification for Industrial Reflector Fittings—Values of Cosine Cubed—Lumen Values of Vacuum and Gas-filled Lamps.

Of factories in general it is said that the efficiency of their lighting systems is indicated by the size of their scrap-heap; this is true for both natural and artificial light.

A considerable sum of money is spent upon the provision of an adequate supply of daylight for an industrial interior; it is realized that before an operator can work properly he must be able to see clearly. At times an insufficient supply of daylight is available, or the wrong kind of daylight is supplied; it is then found that the size of the scrap-heap commences to increase.

One of the authors remembers a case in Coventry where a precision grinder (a grinder who works to very fine limits) always produced a large percentage of scrap when working upon a particular machine. He complained that something was wrong, but did not know what it was. His machine was examined and was found to be quite in order. The operator, without knowing it, was watched, and it was found that he was inclined to make errors only when another machine near-by, a turret lathe, was working. The latter machine was used for turning up crank-shafts, and it was ascertained that as a particular crank turned a distinct flash of light came from it. This was specular reflection, the source being the window. This flicker of light across the eyes of the operator of the grinding machine had such an effect upon his eyes that it caused errors to be made. When the daylight conditions were altered the production of scrap ceased.

If it is an essential to have perfect daylight conditions in an industrial interior, it must be considered more essential for an efficient electric-lighting system to be installed, because the intensity of artificial light can never, for practical purposes, equal daylight. There are few factories in the country to-day, however, where the electric-lighting installation is designed upon scientific lines, and where every requirement is fully met. This was apparent during the Great War, when factories were working night and day; it was found in some cases (and we have verified this) that the night-time production of scrap for a given shop was 300 per cent. more than the daytime scrap for the same shop.

In those days, as indeed in the days before them, lighting units were installed in positions without any consideration of the requirements to be met. Often, when an electrician was sent to 'put up a light,' the first question he asked of the operator was: 'Where do you want this light?' The operator indicated what he considered was the most suitable position, and so an extension to the lighting system came into existence.

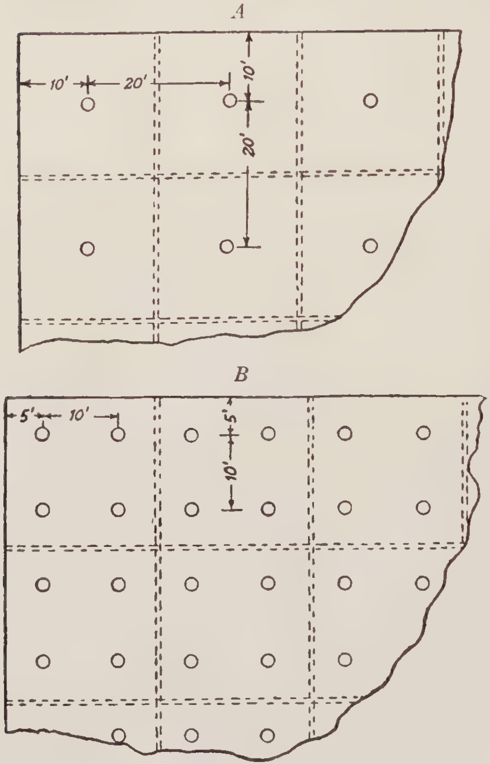

FIG. 36.—TWO DIFFERENT DESIGNS FOR WORKSHOPS OF THE SAME HEIGHT. IN THE FIRST DESIGN THE LIGHT IS NOT DISTRIBUTED SO WELL AS IN THE SECOND ONE.

In 99½ per cent. of the cases where light was installed under these conditions, the reflector, if one had been fitted, would be subsequently found pulled over with string to another position, or a piece of paper had been pasted on the reflector to keep the glare from the eyes, and, especially when bare lamps had been installed, it was not uncommon to see lamps completely enveloped in paper bags. Without further comment on these conditions we submit that the reader can understand to what extent, with such lighting, production must suffer.

An electric-lighting installation for an industrial interior must be designed upon scientific lines if it is to be satisfactory. Just as a power-station engineer, in the interests of efficiency, must give consideration to the size of units, auxiliary apparatus, etc., so the illuminating engineer in an industrial interior must consider such essentials as type of unit, wattage, height, spacing, etc., if he is to meet the requirements of any particular section of industry. It is not a question of how great a light source may be, but of the amount of light from that source which reaches the object to be seen by the illumination.

Considering industries in general—and we have had extensive experience in electrical, engineering, and allied industries—we may say that, owing to the wide variation in factory construction and in industrial processes, it is impossible to lay down any definite rules which will govern a system of standard lighting. Illumination design would be very simple indeed if, within two covers of a book, a design could be found which would apply to any shop or factory interior. We admit that for certain types of shops, and for certain classes or grades of industrial operations, standard lighting designs can be applied. As a general rule, however, these shops and operations are not the most important. It is in important shops, and in connection with important operations, that the illuminating engineer must consider each case separately.

Let us assume, for instance, that an installation has been designed for a pattern-shop to produce, say, an average intensity of 8 foot-candles on the working plane, and that it is giving satisfaction. It is evident that this installation can only give satisfactory results in this shop, or in a shop constructed on exactly the same lines. If this installation were duplicated in another shop, and there were but a slight variation in height or spacing, the resultant illumination would be inefficient.

Again, considering two different shops, we see from Table X that an intensity of 10 foot-candles is necessary in a machine-shop for buffing and polishing, and that 10 foot-candles is necessary in a smithery for fine forging and welding. But, with exactly the same type of shop as far as height, width, and length are concerned, it will be found that an installation suitable for one shop will not be suitable for the other. The chief reason for this is that in the former shop the work, walls, and ceilings are comparatively clean, whereas in a smithery they are black—the result of industrial operation. If the installations were exactly alike the results would be entirely different, not only because reflection factors of walls are different (with the inevitable loss of light due to this cause), but, more important still, the proportion of diffused and reflected light is not the same in both cases. This governs to a very great degree the *kind* of light which is available at the working plane.

There are many important factors which must be considered by the illuminating engineer when designing an installation. He must consider, first, the type of interior to be illuminated—height, length, width, colour of walls; the class of work carried out in the interior; height and spacing of units and wattage of lamps; and, last, but by no means least, the best type of unit to produce the correct proportion of direct and indirect illumination, or directional and diffused illumination, or a combination of the whole.

In a machine-shop, for instance, there is a table to which machine parts of all shapes and sizes are taken for ‘ marking off ’; this is a very important operation, and calls for skill and accuracy. Here the illumination must not be directional even to a slight degree, because the softest shadow on the point of the scriber (a tool for marking off which is set to a micrometer) would prevent the operator from seeing very light lines on his work. In a case like this the operator distinguishes shape, etc., by differences in colour. To ensure clear vision the intensity of light here need not be greater than for less important operations; the distribution of units would, however, be different, because smaller units would give better results than large units with a fairly large spacing ratio.

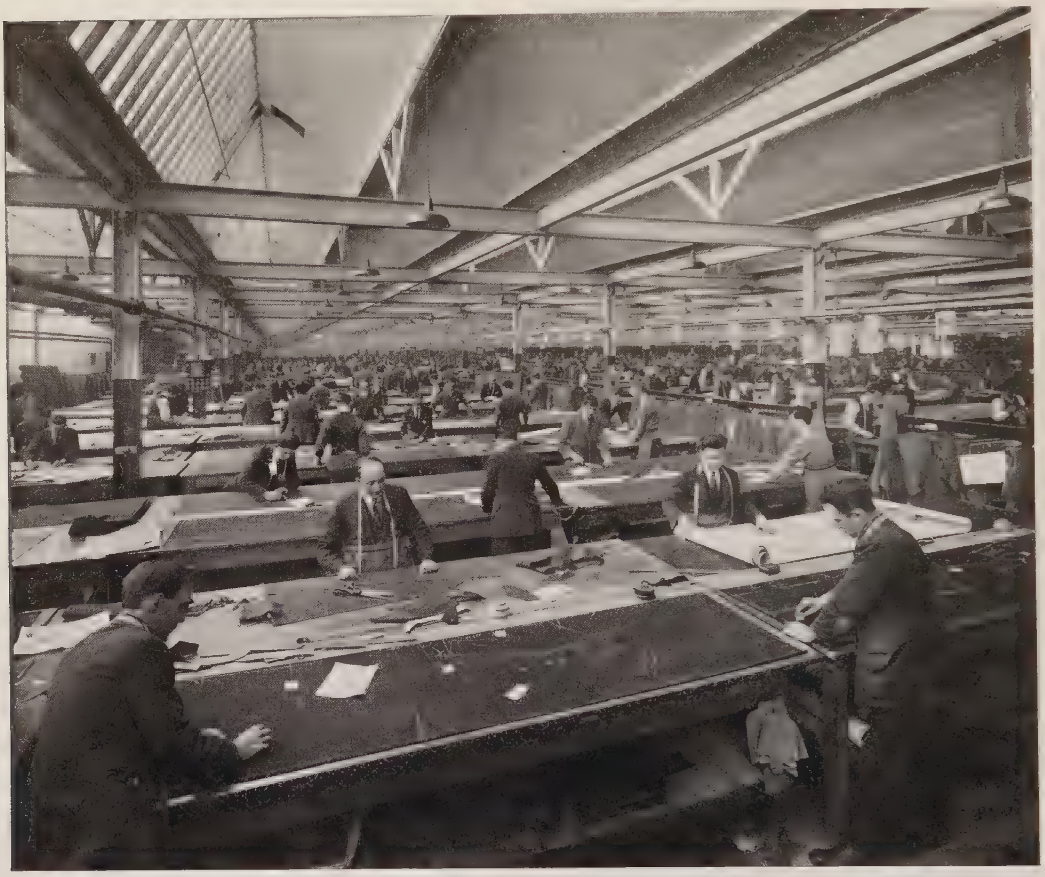

Fig. 37.—A Workshop where Good Lighting is essential.

In some sections of industry it is most essential that the lighting installation shall produce shadows. In a foundry, for instance, where all objects are of the same colour, the intensity of illumination may be even, but it is essential that it should be directional. An iron-moulder, working at a mould, has for material black sand. This as he carries out his work is moulded into various shapes and designs according to the desired kind of casting. If the illumination is too well diffused the whole surface of the mould appears flat and the moulder is deceived, because he cannot accurately determine shape or contour. Here directional lighting will provide that effect of light and shade which will enable the moulder to see his work ; the shadows, however, should not be too harsh.

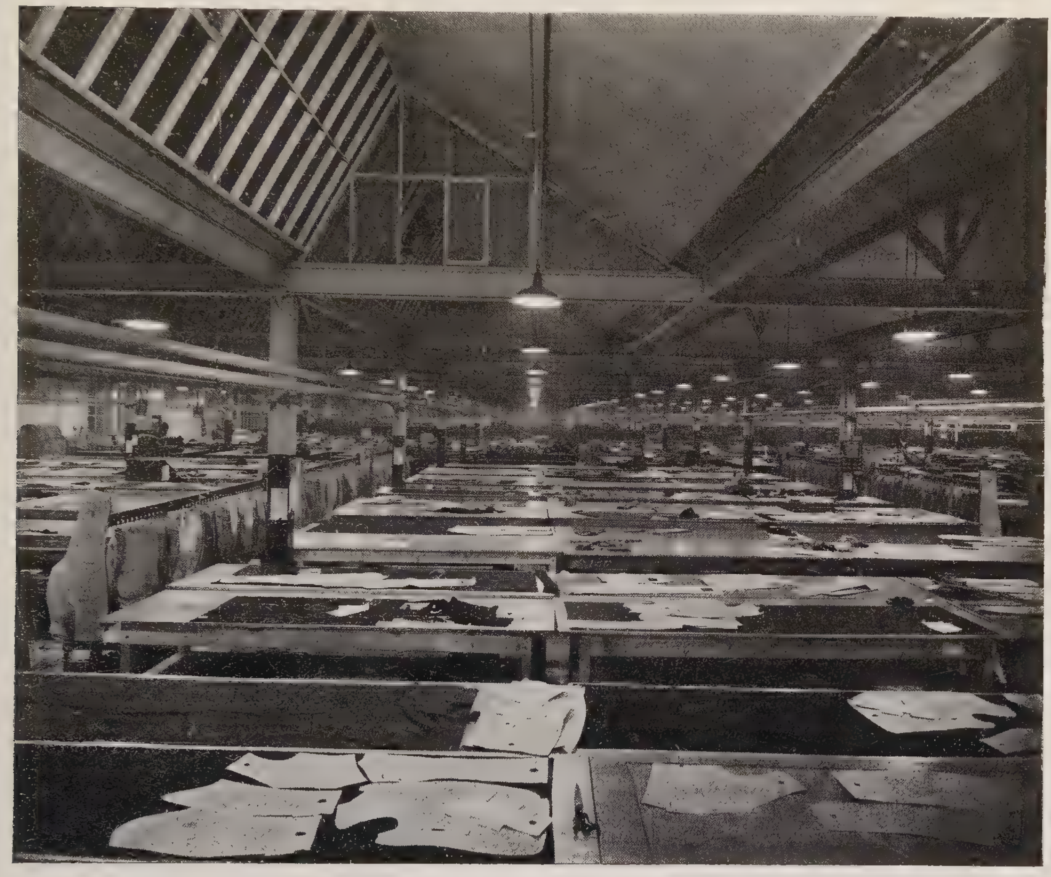

FIG. 38.—THIS ILLUSTRATION OF THE SAME SHOP SHOWS HOW THE REQUIREMENTS ARE MET.

The modern electric lamp is a highly efficient light source, and in the hands of the illuminating engineer can be used to produce direct, indirect, diffused, and directional illumination. For some illuminating purposes different types of lamp filaments assist in obtaining different effects ; in industrial interiors, however, where lamps are mostly of the same type, desired results can only be obtained by the correct use of reflecting equipment.

There is a reflector for every lighting purpose, and we illustrate a few types in Fig. 39. The reflector illustrated at A ensures, by means of the upper reflector, a wide distribution of light, while the lower opal glass effectively screens the lamp filament without interfering with the wide distribution. The reflector illustrated at B is large in diameter and is very deep ; it affords excellent eye protection, and is very efficient in light redirection. It is designed for general lighting.

The reflector illustrated at C is of the distributing type ; it redirects only the light which would normally go in an upward direction. At D a concentrating type of reflector is illustrated. It is smaller in diameter, considering the size of lamp suited to it, than the reflectors previously described. It more completely envelops the light source, and practically conceals it from direct view. It is very suitable for locations where a strongly concentrated light is required on the work, or where it is necessary to mount units fairly high above the working plane.

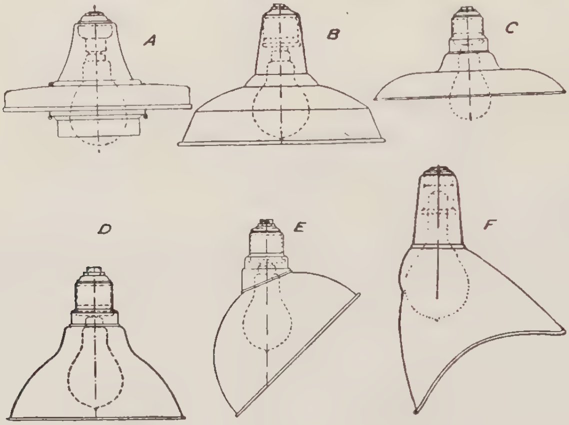

Fig. 39.

At E is illustrated a parabolic angle reflector; this reflector is designed for illuminating both horizontal and vertical areas from a side position. The contour of the unit is such that it not only illuminates the area directly in front, but distributes light to each side in such a manner as to build up in a very marked fashion the illumination between units. It also completely hoods the lamp so as to prevent objectionable direct glare. One of the authors has recently installed a number of these units for illuminating an inside tennis-court, with satisfactory results.

The reflector illustrated at F is an elliptical angle reflector. This is extremely useful in mills, factories, and foundries, etc., where travelling cranes are used, or moving machinery occupies the centre of shops; in this type of interior it is impossible to locate lighting units other than on columns or girders in the shop.

It has been shown that different types of reflectors are used for various purposes; this fact proves that a bare-light source alone is not suitable for any purpose. The reason for this is that, apart from the glare, which is so injurious to the eyes, a very large percentage of the light is wasted in an upward and in a horizontal direction. A reflector to a very large degree controls the light. This is illustrated in Fig. 40, which shows the polar curves obtained from a bare lamp and from the same lamp fitted in a reflector; the curves are A and B respectively, and F is the lamp filament.

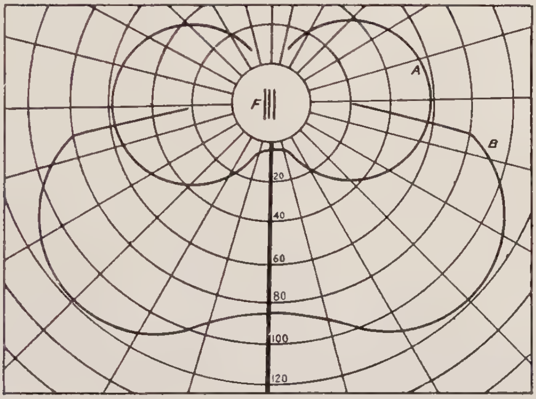

Fig. 40.

The figures placed by the side of the thick vertical line in the centre of the graph indicate candle-power. Considering the curve A, it will be seen that the maximum candle-power is 60, and this is in a horizontal direction; the reason for this is that the largest area of the filament is presented to a space at right angles to the filament. There is no light immediately above the lamp, because it is intercepted by the lamp cap. The minimum candle-power is less than 10, and this is immediately below the filament, the reason being that the minimum area of filament is presented to this direction.

Regarding B, the curve was produced by a type of dispersive reflector; the difference in the curves and their indicated candle-power should be noted. The maximum intensity, 120 candle-power, is reached at approximately 45 degrees below the horizontal; the minimum intensity has increased to 85, and the whole of the light is below the horizontal and in a downward direction.

The position of a lamp filament relative to the reflector controls to a certain degree the point of maximum illumination; once this is fixed, however, the unit can be relied upon to produce candle-powers of the value, and in the direction, indicated by its polar curve. The lamp, however, must always be run at its rated voltage. It is possible that the light distribution between similar units may vary owing to slight differences in height of filament, lamp-holders, etc., but these variations are so slight that they can be ignored when an installation is designed.

One of the authors was in a large institution some time ago, and noticed an engineer making an error which, it is feared, is common among those who are not intimately acquainted with illuminating engineering principles. The engineer was determining the spacing of units with reflectors, by drawing a line from the lamp filaments through the edges of the reflectors to a certain point at which he considered the beams should overlap.

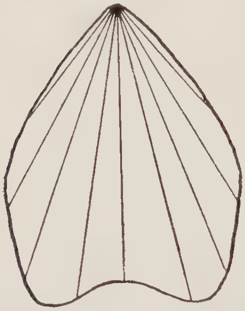

Fig. 41.

This method is incorrect because, irrespective of cut-off, the object should be to obtain the highest intensity of light on the working plane. Let us consider for a moment the polar curve illustrated in Fig. 41. This curve was obtained from the reflector illustrated in Fig. 39, D. It will be seen that the maximum intensity is obtained within 45 degrees from the vertical and very much below the angle of cut-off. It is obvious that, to obtain the maximum intensity on the working plane, the reflector would have to be located fairly high, and this height can only be determined by calculation. If this type of reflector were fitted too low the illumination would be spotty—that is, there would be alternate patches of light of high and low intensity.

The intensity of illumination on the working plane in an industrial interior is always calculated from the maximum intensity as shown by the polar curve, and the height and spacing of units are arranged so that these points meet on the working plane. If the points meet above the working plane the intensity on the working plane is not so high as it should be; if they meet on a theoretical line below the working plane, then the illumination must be uneven. It is because the polar curves of units differ to such a great extent that it is impossible to obtain good illumination in an interior with a mixture of units. This is illustrated in Fig. 42, where two different polar curves are shown; these curves were obtained from the same lamp in different types of reflectors.

Let us assume that two units, each producing polar curve A, form part of a well-designed installation; it will be seen that the point of maximum intensity is approximately on the 45-degrees line. If a line is drawn from each curve, from the top centre through the point of maximum intensity, the two lines will meet at some point below the curves. This point should be on the working plane in an industrial interior. If the maximum intensity on the working plane is 3·5 foot-candles from one unit, then the total intensity will be 7 foot-candles.

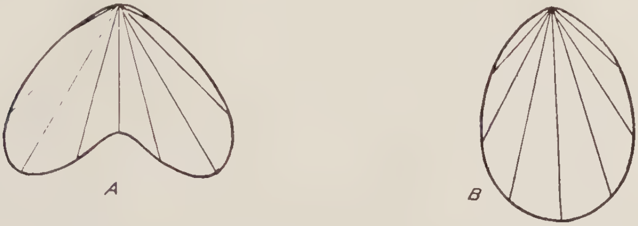

Fig. 42.

If, now, we remove one of the units and replace it by one which produces curve B, the illumination on the working plane will be uneven, for the following reasons:—Unit A is still producing illumination of various intensities at different angles, and, assuming an imaginary working plane, the maximum intensity reaches this point. The maximum intensity of B, however, is immediately under the unit, but this is much higher than the maximum intensity of A. Considering the illumination under each unit, therefore, it will be seen (from measurement) that B is delivering 50 per cent. more than A at this point. If we now consider the angle of maximum intensity on curve A, and compare the intensity with the equivalent angle on curve B, it will be found that the intensity of B is much lower than A. The result is that the intensity from A is still 3·5 foot-candles, and that from B much less than this, say 2 foot-candles; the illumination on the working plane will therefore be 5·5 foot-candles instead of 7 foot-candles.

The reader will do well to consider these two curves with an imaginary working plane; first with two curves A, then with two curves B, and then with A and B. Regarding the latter, if certain foot-candle intensities are assumed a curve can be plotted similar to the one illustrated in Fig. 43. In this graph the length of the working plane is plotted against foot-candles. Commencing on the left with the illumination from A at its maximum (maximum on the left side of the curve), the intensity gradually decreases until it is at its minimum immediately under the unit. The intensity then increases, at first slowly, then rapidly, until maximum intensity is reached at a point immediately under B.

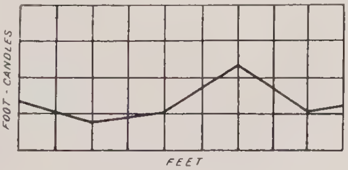

Fig. 43.

Before an installation can be designed it is necessary to know the angle of maximum intensity and the value of the latter in foot-candles; then mounting heights and spacings can be determined to produce even illumination and a desired intensity on the working plane. The importance of correct spacing, however, cannot be too strongly emphasized.

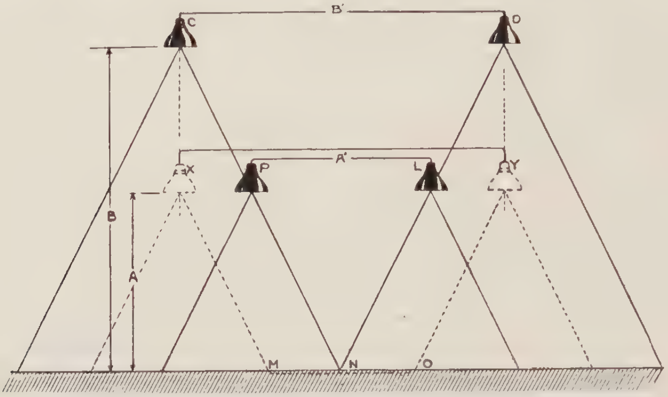

Fig. 44.

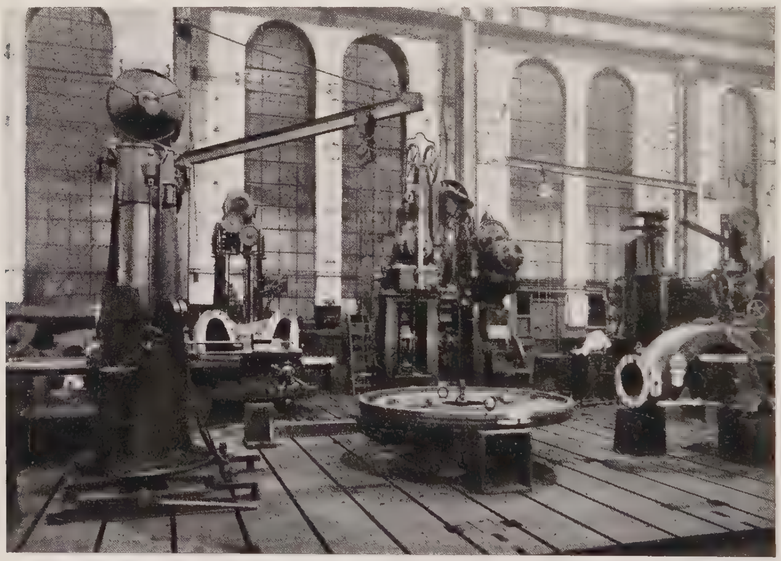

Fig. 45.—The Essentials of Good Illumination are embodied in this Installation.

The effect of incorrect spacing is illustrated in Fig. 44. This illustration shows the proper ratio between spacing distance and mounting height which must be observed to obtain uniform illumination. Let us assume that two reflectors P and L are A′ feet apart and A feet high; this distribution will secure uniform illumination. If the reflectors are moved further apart, to positions X and Y, the points of maximum distribution occur at M and O, causing a dark area between them, and therefore uneven illumination. If the reflectors are located at C and D, they must have a mounting height B if uniform illumination is to be secured. In this case, however, the candle-power of the lamps must be increased if the same illumination is desired at the working plane.

In illumination problems it is necessary to distinguish between light intensity and the illumination upon the working plane. The intensity of the light source is termed candle-power, and it has for comparison the intensity of light from a standard candle, or from an incandescent lamp which has been calibrated to a standard candle. The intensity of illumination upon the working plane is measured in foot-candles. If a lamp gives 16 candle-power in a downward direction, and a table is placed immediately under the lamp, at a distance of 1 foot, the illumination over an area of 1 square foot would be 16 foot-candles.

A simple rule for calculating the illumination from a bare lamp on a surface immediately below it is: divide the candle-power of the source by the distance from the surface squared.

This is:

$$\text{Illumination} = \frac{\text{candle-power}}{\text{distance}^2},$$

or

$$\text{Candle-power} = \text{illumination} \times \text{distance}^2,$$

or

$$\text{Distance}^2 = \frac{\text{candle-power}}{\text{illumination}}.$$

and

$$\text{Distance} = \sqrt{\frac{\text{candle-power}}{\text{illumination}}}.$$

Example.—A lamp gives 20 candle-power in a downward direction. If this is suspended at a height of 5 feet above a table, calculate the illumination on the table.

$$\begin{aligned}\text{Illumination} &= \frac{\text{candle-power}}{\text{distance}^2}\\ &= \frac{20}{5^2} = \frac{20}{25}\\ &= \cdot 8 \text{ foot-candle.}\end{aligned}$$

Example.—If a 50-candle-power lamp provides an illumination of 2 foot-candles on a table, at what height is the lamp above the table ?

$$
\begin{aligned}
\text{Distance} &= \sqrt{\frac{\text{candle-power}}{\text{illumination}}} \\
&= \sqrt{\frac{50}{2}} \\
&= \sqrt{25} \\
&= 5 \text{ feet.}
\end{aligned}
$$

Example.—In the above example, if the height were increased to 10 feet, what candle-power lamps would be required to give the same illumination ?

$$
\begin{aligned}
\text{Candle-power} &= \text{illumination} \times \text{distance}^2 \\
&= 2 \times 10^2 \\
&= 2 \times 100 \\
&= 200 \text{ candle-power.}
\end{aligned}
$$

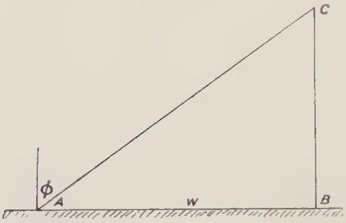

Fig. 46.

The calculations are more complicated when determining illumination at points from the vertical. Let us consider Fig. 46, where W is the working plane, C is a light source some distance above it, and ABC is a right-angled triangle. If the candle-power of the lamp is 1000 and the height of the source 10 feet, the intensity at B

$$= \frac{1000}{10^2} = \frac{1000}{100} = 10 \text{ foot-candles.}$$

At point A, however, it will be :

$$
\begin{aligned}
\text{Illumination} &= \frac{\text{candle-power}}{AC^2} \\
&= \frac{\text{candle-power}}{AB^2 + CB^2}.
\end{aligned}
$$

Assuming A to be 30 feet from B, and using the same values as before, the illumination on a plane normal to CA will be :

$$
\begin{aligned}
\text{Illumination} &= \frac{\text{candle-power}}{AB^2 + CB^2} \\
&= \frac{1000}{30^2 + 10^2} \\
&= \frac{1000}{900 + 100} \\
&= \frac{1000}{1000} \\
&= 1 \text{ foot-candle.}
\end{aligned}
$$

The illumination at A on the plane W is :

$$\text{Illumination} = \frac{\text{candle-power}}{\text{distance}^2} \times \cos \phi,$$

where ϕ is equal to angle ACB.

$$\text{Distance}^2 = \text{AC}^2$$
$$= \text{CB}^2 + \text{AB}^2.$$

Now $$\text{AC} = \sqrt{\text{CB}^2 + \text{AB}^2}.$$

$\therefore$ $$\cos \phi = \frac{\text{CB}}{\sqrt{\text{CB}^2 + \text{AB}^2}}.$$

Substituting for values, we find that the illumination at A is :

$$\frac{1000}{10^2 + 30^2} \times \frac{10}{\sqrt{10^2 + 30^2}}$$
$$= \frac{1000}{1000} \times \frac{10}{\sqrt{100 + 900}}$$
$$= 1 \times \cdot 3$$
$$= \cdot 3 \text{ foot-candle (approx.)}.$$

The calculations are still more complicated when a reflector is fitted to the lamp, Fig. 47, because the distribution of light at all angles must be taken into consideration. The illumination is found by the formula :

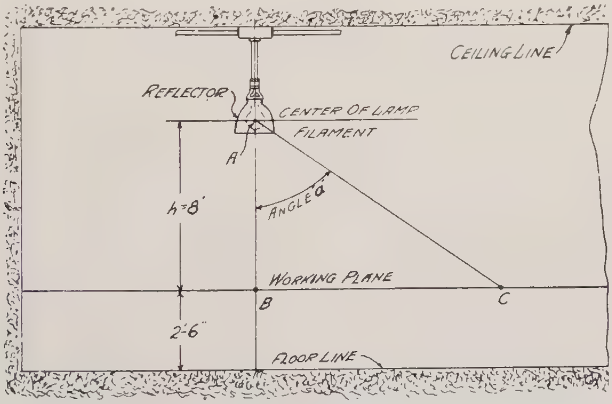

Fig. 47.

$$\text{Illumination} = \frac{\text{candle-power}}{h^2} (\cos^3 \phi),$$

where h is the distance from the filament to the working plane, and ϕ is the angle a shown in Fig. 47.

Example.—Calculate the horizontal illumination on the working plane from a unit fitted at a distance of 8 feet above it; the output of the unit is 920 lumens.

The answer is obtained by applying this formula and plotting the results in the form of a graph as illustrated in Fig. 48. The graph applies to one unit only; when more than one unit is considered, another curve is plotted from the right so that the two curves cross at a certain point, from which the foot-candle values are obtained by the simple process of addition. The values of $\cos^3 \phi$ for various angles are given in Table IV.

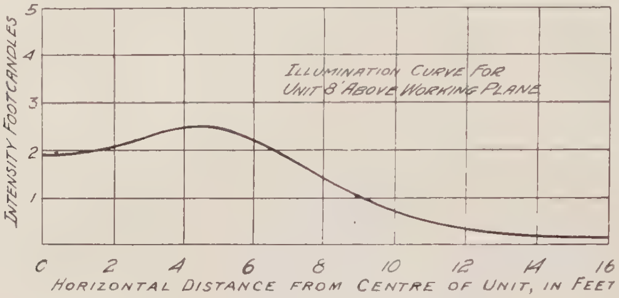

Fig. 48.

Fig. 49.—A Well-illuminated Boiler-house Interior.

The above methods of calculation are tedious, and, if slight mistakes are made in the earlier stages, errors in the results are likely to be large. A simple method of calculation is as follows :

$$L=\frac{A\times I}{K},$$

or

$$A\times I=L\times K,$$

or

$$K=\frac{A\times I}{L},$$

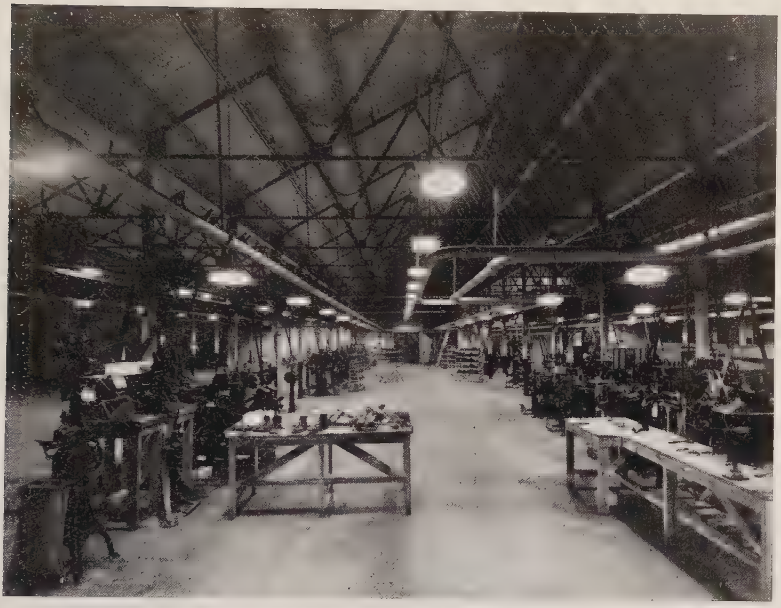

FIG. 50.—AN INSTALLATION IN WHICH GOOD LIGHTING IS MANIFEST.

where L is the total lumens, A is the area in square feet, I is the intensity in foot-candles, and K is a constant the value of which depends upon the coefficient of utilization. The latter depends upon the colour of walls, as shown in Table II.

In an industrial interior the reflection factors of ceilings can be ignored, because the reflector is opaque, and in effect acts as the ceiling. In the above formula the total lumens emitted by a lamp can be obtained by multiplying the mean spherical candle-power by 4π, or by 12·57. The whole of this light is not effective, because a certain proportion is absorbed in the reflectors and walls.

TABLE II

Colour of Walls	Coefficient of Utilization, per cent.
Light	60
Medium . . .	50
Dark	40

There are two simple methods of computing resultant illumination: watts per square foot, and lumen.

Watts per square foot.—The following table gives the ratio between foot-candles and watts per square foot:

TABLE III

Foot-candles	Watts per square foot
·5	·08
1·0	·15
1·5	·22
2·0	·29
2 5	·37
3·0	·44
3·5	·51
4·0	·59
4·5	·66
5·0	·73
6·0	·88
7·0	1·04
8·0	1·18
9·0	1·32
10·0	1·47

In the design of an installation by this method the desired foot-candle intensity is ascertained from Table X. If the intensity is 4 foot-candles the wattage per square foot is 0·6 watt; if the intensity is 8 foot-candles the wattage per square foot is 1·18 watts. From this it will be seen that:

$$\text{Total watts} = \text{watts per square foot} \times \text{area},$$

and

$$\frac{\text{Total watts} \times \text{coefficient of utilization}}{\text{number of units}} = \text{watts per unit.}$$

The Lumen Method.—In this method the effective lumens are found by :

$$\text{Effective lumens} = \frac{\text{intensity} \times \text{area of interior}}{0{\cdot}5}.$$

The intensity for the interior or operation is found as before from Table X. Regarding the area of the interior, the case will be met by dividing the interior into squares or rectangles and considering this with the intensity. From this the effective lumens per point can be calculated.

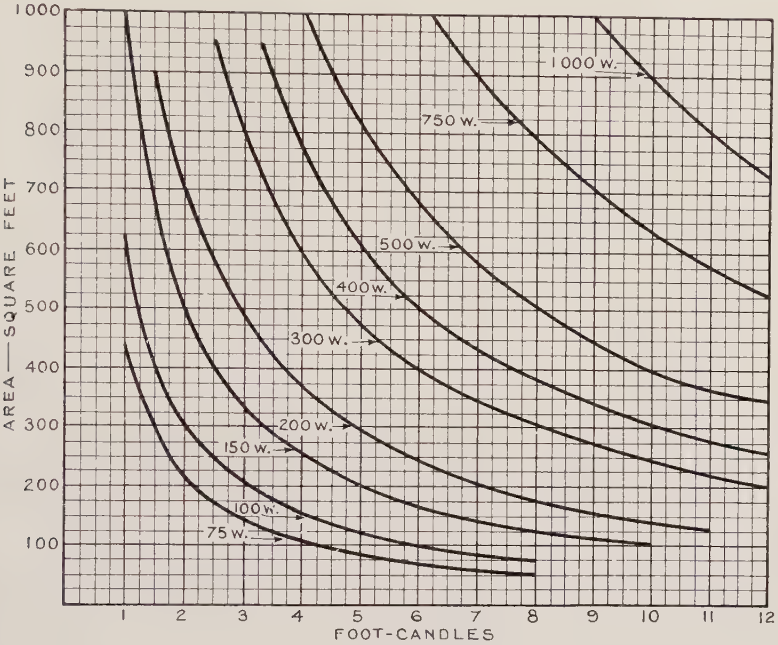

FIG. 51.

With regard to spacing, this may be considered as approximately $1\frac{2}{3}$ times the height of the unit above the working plane.

An illumination computation diagram, based on a coefficient of utilization of 50 per cent., is given in Fig. 51. Here the relation between watts per point, area per bay, and foot-candle intensity is shown.

Example.—An industrial interior is divided into bays, each of which has an area of 400 square feet. If the desired foot-candle intensity is 8 foot-candles, what size units would you install, and how would you locate them ?

Answer.—Referring to Fig. 51, it will be seen that at the point upwards where 8 foot-candles and 400 square feet area (horizontal) meet, the wattage of the nearest lamp is 400 watts. In countries where 400-watt lamps are manufactured, one unit per bay would meet the case as illustrated in Fig. 36, A. In England, where at the moment of writing this type of lamp is not manufactured, four 100-watt units per bay, as illustrated in Fig. 36, B, will meet the requirements.

From the data, formulæ, tables, and graphs given in this section it is possible to design an installation for any industrial interior where any degree of uniform intensity of light is desired.

Maintenance.—After an installation has been in use for some time it is often condemned as being inefficient ; one often hears the complaint that the 'light is not as it was.' The real cause of this—bad maintenance—is not considered, and the person responsible for the design of the installation is blamed.

We have carried out tests to determine the loss in efficiency in badly maintained installations, and we find that the average loss is approximately 10 per cent. per month. Our tests were carried out in three shops : (1) a coppersmith's shop ; (2) a boiler shop ; (3) a smithery. The tests were carried out over a period of five months during last winter, and the losses are shown in Fig. 52.

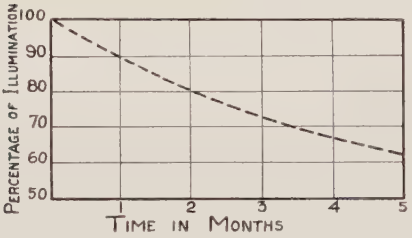

FIG. 52.

The chief cause of the losses was dirty equipment, such as lamps and reflectors, and using lamps after they had run their useful life. Regarding the latter, it is a fallacy of economy to maintain lamps in use after they have rendered 1000 hours' service. Indeed, it may be sound economy to 'scrap' them after they have been in use for 600 hours ; the cost of lamp renewals is such a small proportion of their energy consumption that the decreased light output after this time warrants their disuse.

In every installation a proper maintenance schedule should be formulated ; this should be conscientiously carried out so that at any time during the winter months the condition of lamps and reflectors is the same as when the installation was first completed. It is only in this way that maximum efficiency can be maintained.

BRITISH STANDARD SPECIFICATION FOR INDUSTRIAL REFLECTOR FITTINGS FOR ELECTRIC LIGHTING. (No. 1.)[1]

(No. 1.—Open Dispersive (Vitreous Enamel) Type for Direct General Lighting for use with Gas-filled Electric Lamps complying with the requirements of B.E.S.A. Specification No. 161—1924.)

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General.

1. This specification covers seven sizes of British standard industrial circular reflector fittings for direct general lighting, No. 1, open dispersive type, for use with gas-filled lamps. They are designated according to the nominal consumption of the lamps for which each is suitable, as set out, with some other details, in the table below:—

1	2		3		4		5	6	7
Designation	Nominal diameter		Minimum effective interior diameter		Minimum thickness of steel used for making Reflector Fitting		Particulars of suitable lamps complying with the requirements of B.E.S.A. Specification No. 161—1924		
							Mean Light Centre Length *		Type of Lamp-holder
	in.	† cm.	in.	† cm.	in.	† mm.	mm.	in.†	
For 40-watt lamps . .	10	25·4	9¼	23·5	·018	·46	85	3·4	B.C.
For 60-watt lamps . .	12	30·5	11¼	28·6	·018	·46	85	3·4	B.C.
For 100-150-watt lamps .	14	35·6	13¼	33·7	·018	·46	120	4·8	B.C.
For 200-watt lamps . .	16	40·6	15¼	38·7	·018	·46	150	5·9	E.S.
For 300-watt lamps . .	18	45·7	17	43·2	·028	·71	180	7·1	G.E.S.
For 500-watt lamps . .	18	45·7	17	43·2	·028	·71	205	8·1	G.E.S.
For 1000-1500-watt lamps .	20	50·8	19	48·3	·028	·71	250	9·9	G.E.S.

* The light centre length tolerances allowed in B.E.S.A. Specification No. 161—1924 do not apply in connection with the tests referred to in clauses 4, 5, and 6.

† These equivalent dimensions are approximate only.

The reflector shall be fitted with a lamp-holder of the type given in column 7 of the table, and shall satisfy the requirements of this specification when a gas-filled lamp of the size given in column 1 of the table is used in the holder provided. All lamp-holders shall comply, in so far as is necessary to secure interchangeability of lamps, with the dimensions given in the appropriate B.E.S.A. specification.

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[1] Copies of this specification can be obtained from the British Engineering Standards Association, 28 Victoria Street, London, S.W. 1. Price 1s. net. ; post free, 1s. 2d.

> *Note.*—Under licences obtained from the Main Committee of the British Engineering Standards Association, the British Standard mark BESA may be marked on the reflector fitting by British manufacturers to show that the reflector fitting complies with the British Standard Specification. Reflector fittings so marked shall in addition bear the number and year of issue of this specification, *i.e.* 232—1926.
>
> Particulars of the conditions under which licences are granted may be obtained from the Secretary of the British Engineering Standards Association, 28 Victoria Street, S.W. 1.

Material.

2. Unless otherwise specified, the reflector shall be made of steel of not less than the thickness given in column 4 of the table in clause 1, and shall be coated inside and outside with not less than three uniform smooth coats of vitreous enamel.

Dimensions.

3. The effective interior diameter of the reflector fitting, *i.e.* the diameter measured within the mouth, shall be not less than that given in column 3 of the table in clause 1.

Luminous Output.

4. The total luminous output of the combined reflector fitting and lamp shall be not less than 60 per cent. of the luminous output of the lamp alone.

The test lamp for the purpose shall be a normal-type gas-filled lamp, with clear-glass bulb, complying with the requirements of B.E.S.A. Specification No. 161—1924, of the size given in column 1 of the table in clause 1, and having a filament free from sag. The light centre length shall be as given in columns 5 and 6 of the table, the lampholder being in the normal fixed position in the reflector fitting.

> *Note* 1.—Measurements of luminous output may be made either by means of a photometric integrator or by a point-to-point method (see Appendix).
>
> *Note* 2.—An efficiency of about 70 per cent. was obtained with this type of reflector under the conditions which were usual formerly The conditions have been altered in order to reduce the amount of glare from the reflector fitting and so comply with the recommendations contained in the Second Report of the Departmental Committee on Lighting in Factories and Work shops, 1921.

Distribution of Light.

5. The distribution of light from a reflector fitting intended for use with a 100-watt lamp or over shall, when the reflector fitting is fitted with the appropriate lamp, be such that the ratio of the maximum

candle-power in any direction within 15 degrees of the downward vertical axis to the average of the candle-powers at 25, 35, and 45 degrees from the downward vertical axis is not greater than 1·35.

Note.—The distribution of light herein contemplated is suitable for use in installations in which the spacing of the lamps is 1½ times the height.

Angle of Cut-off.

6. When the reflector fitting is fitted with the appropriate lamp as defined below, no part of the filament shall be visible when viewed from a point in any direction making an angle exceeding 70 degrees[1] from the downward vertical axis of the reflector fitting.

The test lamp for the purpose shall be a normal-type gas-filled lamp, with clear-glass bulb, complying with the requirements of B.E.S.A. Specification No. 161—1924, of the size given in column 1 of the table in clause 1, and having a filament free from sag. The light centre length shall be as given in columns 5 and 6 of the table, the lamp-holder being in the normal fixed position in the reflector fitting.

SELECTION FOR TESTING.

Note.—Agreement should be reached before the order is placed in regard to the carrying out of tests for compliance with this specification.

In view of the cost of carrying out such tests, it is not expected that they will be called for except in the case of purchases of 200 reflectors or over. It is essential, therefore, that the manufacturers should have their products tested sufficiently frequently to ensure that they are in accordance with the specification. Evidence of such tests should, as a general rule, satisfy the purchaser as to the quality of the reflectors.

Selection for Testing of Reflector Fittings under Clauses 1, 2, 3, *and* 6.

7. For test under clauses 1, 2, 3, and 6, reflector fittings shall be selected at random as follows :—

From batches of 200 to 500 reflector fittings : 5 per cent. (fractions being neglected).

From batches of more than 500 reflector fittings : 2 per cent. plus 15 (fractions being neglected).

If any of the reflector fittings selected fail to pass the requirements of clauses 1, 2, 3, or 6, they shall be deemed not to have satisfied the requirements of this specification. If more than 10 per cent. of those selected fail to pass such requirements, two further selections of a similar number shall be made ; if more than 10 per cent. of either of these selections fail to satisfy the requirements, the whole batch shall be deemed not to comply with this specification.

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[1] This figure complies with the recommendation of 20 degrees from the horizontal for light sources at distances of not less than 6 feet, contained in the Second Report of the Departmental Committee on Lighting in Factories and Workshops, 1921, but may be altered later.

Selection for Testing of Reflector Fittings under Clauses 4 and 5.

8. For test under clauses 4 and 5, reflector fittings shall be selected at random as follows :—

From batches of 200 reflector fittings and over : 1 per cent. (fractions being neglected).

If the average of the values of the luminous output of the reflector fittings tested does not satisfy the requirements of clause 4, or the average ratio indicating the distribution of light does not satisfy the requirements of clause 5, two further selections of a similar number shall be made. If the results from either of these selections do not satisfy the requirements of clauses 4 or 5, the whole batch shall be deemed not to comply with this specification.

APPENDIX.

Methods of Efficiency Measurement.

(*a*) *Photometric Integration Method.*—When a photometric integrator is used, the diameter (or the least distance between opposite sides in the case of a non-spherical integrator) shall be not less than four times the maximum diameter of the reflector fitting. All externally visible opaque parts of the lamp or reflector fitting and its support shall be whitened. or covered with a white material, provided that the amount or distribution of the light flux from the lamp or reflector fitting is not thereby affected.

(*b*) *Point-to-Point Method.*—When a point-to-point method is used, the distance between the light centre of the lamp and the photometer head shall be not less than eight times the diameter of the reflector fitting. The total flux shall be deduced from measurements of candle-power in two vertical planes at right angles to each other one of which includes the axis of symmetry of the lamp filament system. Measurements shall be made in each plane on one side of the downward vertical axis only, and at the following angles from that axis, viz. : (i) at 0, 10, 20 . . . 180 degrees, or alternatively (ii) at the twenty Russell angles given in the following table. In the latter case the arithmetical average of the candle-power values shall be taken as the mean luminous output.

Russell Angles, measured from the Downward Vertical Axis.

18·2°	92·9°
31·8°	98·6°
41·4°	104·5°
49·5°	110·5°
56·6°	116·7°
63·3°	123·4°
69·5°	130·5°
75·5°	138·6°
81·4°	148·2°
87·1°	161·8°

TABLE IV

VALUES OF COSINE CUBED

The table below gives for various angles the values of the cosine cubed. These values, when used in connection with the formula, make it possible to determine the illumination from the lighting unit at any position in an interior. The angle designated is the angle between the direction of the ray of light under consideration and the perpendicular line passing through the axis of the lamp.

Angle Degrees	Cosine Cubed	Angle Degrees	Cosine Cubed	Angle Degrees	Cosine Cubed
1	1·000	31	·630	61	·114
2	·998	32	·610	62	·103
3	·995	33	·590	63	·0936
4	·993	34	·570	64	·0842
5	·988	35	·550	65	·0754
6	·983	36	·529	66	·0671
7	·978	37	·509	67	·0596
8	·971	38	·489	68	·0526
9	·963	39	·469	69	·0460
10	·955	40	·449	70	·0400
11	·945	41	·429	71	·0345
12	·935	42	·410	72	·0295
13	·925	43	·391	73	·0250
14	·913	44	·372	74	·0209
15	·901	45	·353	75	·0173
16	·888	46	·335	76	·0142
17	·874	47	·317	77	·0114
18	·860	48	·300	78	·00900
19	·845	49	·282	79	·00695
20	·829	50	·265	80	·00523
21	·813	51	·249	81	·00383
22	·797	52	·233	82	·00270
23	·780	53	·218	83	·00181
24	·762	54	·203	84	·00114
25	·744	55	·189		
26	·726	56	·175		
27	·707	57	·161		
28	·688	58	·149		
29	·668	59	·137		
30	·649	60	·125		

TABLE V

LUMEN VALUES OF VACUUM AND GAS-FILLED LAMPS

Vacuum-type Lamps			Gas-filled Lamps		
Voltage	Wattage	Lumen Value	Voltage	Wattage	Lumen Value
50 to 80	20	158·5	25	15	168
	30	248·38	25	30	360
	40	332·47	25	60	750
	60	520·64	25	100	1,300
			50/65	30	360
100 to 130	20	160·77	50/65	60	750
	30	251·65	50/65	100	1,300
	40	336·87	50/65	150	2,100
	60	527·56	50/65	200	2,800
			50/65	300	4,600
			50/65	500	8,500
200 to 250	20	145·18			
	30	225·5	100/130	40	400
	40	324·44	100/130	60	750
	60	510·84	100/130	100	1,300
			100/130	150	2,100
			100/130	200	2,800
			100/130	300	4,600
			100/130	500	8,500
			100/130	1000	18,000
			100/130	1500	28,000
			200/250	60	550
			200/250	100	1,200
			200/250	150	1,800
			200/250	200	2,500
			200/250	300	4,200
			200/250	500	7,300
			200/250	1000	16,500
			200/250	1500	26,000

CHAPTER IV

LIGHTING DESIGNS FOR SHOPS AND STORES

In General—The Attractive Power of Shop Windows—Requirements to be Met —Methods of Shop-Window Lighting—Distribution of Light—Polar Curves—Experimental Curves—Installation Design—Colour Screens—Window Floods—Spot Lights—Light Intensities for Stores—Lighting Designs for Stores: Design 1, Design 2, Design 3, Design 4, Design 5, Design 6, Design 7, Design 8, Design 9, Design 10, Design 11, Design 12—Present Standards of Foot-Candle Illumination for Shops—For Commercial and Public Buildings—For Industrial Interiors—Choice of Reflecting Equipment—Guide to the Selection of Equipment—Spacing —Mounting Height—Room Index—Coefficients of Utilization—Ratings and Dimensions of Gas-filled Lamps.

In General

With the advent of electricity for lighting purposes there was no one who realized the advantages of the new illuminant more than the shopkeeper. With gas jets, the means of lighting then in vogue, the illumination in a shop window was limited by many factors, the chief of which, perhaps, was the necessity for fitting gas brackets at as great a distance as possible from the goods displayed, in order to minimize the risk of fire and the disastrous effect of heat upon certain classes of goods. In this way the number of gas brackets which could be installed in a shop window was limited, and the meagre amount of illumination upon the goods left everything to be desired.

It is not exceeding facts in any way to say that the shopkeeper grasped the benefits of electric light with both hands. Thus we saw, in the first electric-light installations for shop-window illumination, a large number of ceiling roses fitted in each window, each accommodating many lengths of flexible wire to which were connected lamps and lamp-holders; the wires were hung in festoons, and the lamps, which from a generation of heat point of view were comparatively safe, were placed as near as possible to the goods displayed.

This was considered good lighting. The lamps were placed indiscriminately, some high, some low, some in front of the windows and some at the sides; the fact that a bright light in the line of vision reduces one's ability to see was not understood at the commencement of the electric-lighting era. A large proportion of the work of the illuminating engineer of to-day is to point out defects in old-time lighting systems, and to show how installations designed upon scientific principles will not only well illuminate the goods but will considerably enhance their appearance.

From investigations we have made it has been ascertained that shop windows have a certain value, not only to the proprietors in whose premises the windows are situated, but to the various departments to which windows are allocated. The value of shop windows will, of course, vary according to the city, town, or district in which the business premises are situated. It has been definitely ascertained, however, that the average value of the windows of a well-known company, situated in High Street, Kensington, London, is £250 per window per week. That is, each department which has a window display is charged at the rate of £250 per week for that window. At times, when displays are being changed and the window is 'out,' a process which occupies more than one day to carry out, it has been found that a loss of more than £200 has been incurred. On the face of these facts it is not fallacy to advocate good lighting in shop windows after nightfall, when the viewing of goods can be continued and profits of the establishment therefore increased; this statement is based upon the fact that a person stopping to look in a window must be attracted, and that attraction is 80 per cent. of a sale.

The Attractive Power of Shop Windows

Regarding the attractive power of shop windows we may say that, over a period of four months during the winter of 1925-26, we carried out a number of tests in Birmingham, London, and Manchester, in an effort to determine the magnitude of the attractive power of shop windows illuminated with various intensities of light. In all, one hundred tests were made in good and bad weather, when crowds were large and small, on week nights and Saturday evenings, and even during the Christmas holiday period; the whole of the results were tabulated, and in this way a very fair average was obtained.

The minimum intensity of light in any window was 15 foot-candles, and it was found that, in comparison with windows illuminated to an intensity of 40 foot-candles, 30 per cent. more people slowed up or actually stopped to view the displays in the windows illuminated with the higher intensities of light. Windows illuminated to an intensity of 100 foot-candles attracted 70 per cent. more people than the windows illuminated to an intensity of 15 foot-candles, On one occasion we carried out observations upon three windows situated side by side; the intensity of illumination in the windows was 50, 17, and 80 foot-candles respectively; the window with the lowest intensity of light was situated in the centre of the other two. Our observations were carried out over a period of half an hour, with the following results :—

50 foot-candles . .	108 persons stopped.
17 ,, . .	32 ,, ,,
80 ,, . .	212 ,, ,,

Comment upon these figures is unnecessary ; they speak for themselves.

REQUIREMENTS TO BE MET

Adequate illumination in a shop window or any interior is neither more nor less than the installation of suitable lighting units, installed after due consideration has been given to the whole of the essentials which will meet requirements ; of these essentials height, spacing, and the correct type of lamps are the most important. In the remainder of the essentials is embodied four simple principles ; these, expressed briefly, are :—

1. All light sources should be concealed ; this is an essential if glare is to be avoided.
2. The lighting units should be located in such positions, and be of such types, that the display—not the ceiling or pavement—is illuminated.
3. The light must be perfectly controlled ; this means that the whole of the light rays which emanate from the light source are collected, and directed in certain planes, thus concentrating the whole of the light upon the goods displayed.
4. The illumination should be of high intensity, especially in main thoroughfares where the streets are well illuminated. A high intensity of light in the street would make a poorly illuminated window look almost dark.

Regarding methods of shop-window lighting, a walk along a main street in any of our cities or towns will show that their name is legion. It is obvious, however, that some of these methods must be better than others, and that some must be extremely bad. The reason why these methods came into existence is not very difficult to trace ; a lighting unit has been merely considered as a means to obtain light irrespective of its suitability to meet certain requirements. It is for this reason that we see bare lamps, ordinary domestic fittings, and other unsuitable units installed in shop-window lighting systems. We will consider the effect of a few of these.

Installations are in existence where bare lamps accommodated in opal shades are located behind pelmets; the reflections of the filaments of these lamps can be seen in the mirrors at the back of the windows. This is, in effect, similar to an installation consisting of bare lamps ; glare is in evidence, and the vision of persons looking into the windows is impaired.

In many cases a diffusing type of unit has been installed ; this is usually of the semi-indirect type, or the enclosing type, of opal glass. These units are totally unsuitable for shop-window lighting, because, apart from the excessive waste of illumination, the light is too well diffused. In many displays the chief essential is to display goods under actual wearing conditions ; for this purpose expensive models are used in displays to give the would-be purchaser an impression of the goods.

Let us take, for instance, the case of a model which is displaying an evening dress : it is of a certain colour, and it hangs in folds, etc., according to its design ; the essential of its display is that the folds and trimming, etc., shall be outstanding. Where light is too well diffused the effect of folds is lost, and the dress, instead of appearing in a definite shape, appears too flat. Such lighting tends to decrease sales, because a true conception of the goods is not conveyed to the person viewing the display.

Methods of Shop-Window Lighting

In general, there are two methods of shop-window lighting : flexible and fixed. In the flexible method of lighting a number of small units are fixed in two or more rows upon special brackets situated on the ceiling immediately in front of the pelmet. The units in the rows are connected up to various circuits, so that, when one or more of the latter are switched on, various lighting effects can be obtained.

In Fig. 53 is illustrated a typical installation of flexible lighting. The photograph is of one of the windows of the numerous shops of the well-known Brighton outfitters, Messrs. Hannington ; the photograph was taken from the inside of the window looking towards the street in order that the design of the installation can be clearly seen.

In this installation forty reflectors of the one-piece type are divided into three rows. The top row consists of eight reflectors, each equipped with gas-filled lamps. The second and third rows are comprised of thirty-two reflectors, each fitted with colour screens ; the colours are green, blue, red, and amber. The units situated above these rows are window-floods ; these, also, are fitted with colour screens. Attention is drawn to the small unit situated between the fifth and sixth reflectors in the first row ; this is a window-spot the beam of which is projected upon a special feature in the display.

The whole of the units are connected up to a motor-driven flasher, such as is illustrated in the section of this work which deals with electric signs. The drum and contacts are designed so that one or more circuits are connected to the supply in a certain order and in this way a sequence of colour effects is obtained. A typical sequence of effects is as follows :—From the off position the first contact floods the window with soft amber-coloured light; after a few moments this is supplemented by red and, a few moments later, green. Amber is now switched off and the window is illuminated with red and green mixed. Green now disappears, to be replaced by blue; and as the controller continues the sequence, red and blue are mixed and the window-floods are operating intermittently. As each change occurs, the spot-light illuminates the centre of attraction in the display. As a general rule, each sequence is terminated at the 'off' position; that is, at the point where the units containing the clear lamps are projecting white light on the display.

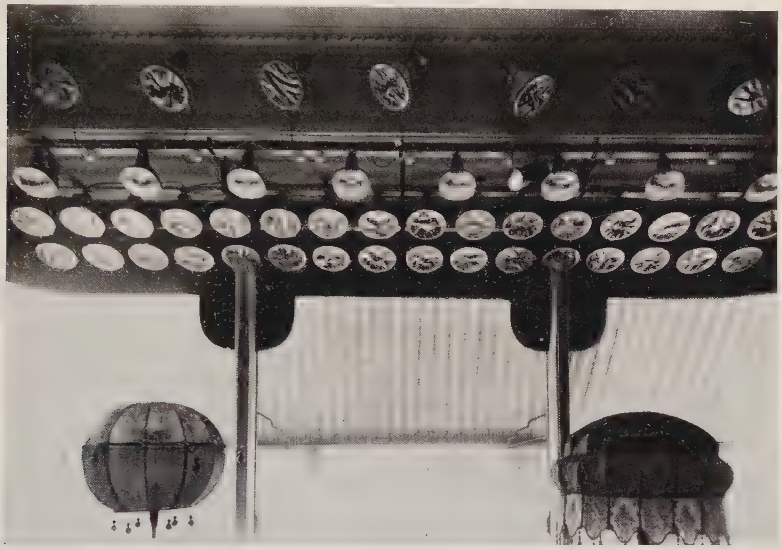


FIG. 53.—A TYPICAL INSTALLATION OF FLEXIBLE LIGHTING.

In Fig. 54 is illustrated the same window, but the photograph this time was taken from the street in order that the display can be seen. To enable this photograph to be taken the flasher was stopped at the point when blue and red were the predominating colours in the window illumination; the colours in the display were chiefly red, blue, and green, with a small percentage of cream. As will be seen from the section of this work which deals with colour vision, the colour of the goods in the display is emphasized and the beauty of the goods is enhanced. That the installation is efficient and attractive is apparent from the illustration, in which every article of the display can be clearly seen.

The fixed-method lighting is usually installed when it is desired to secure high intensities of light. The reflectors adopted in this case are much larger than those used under ordinary conditions;

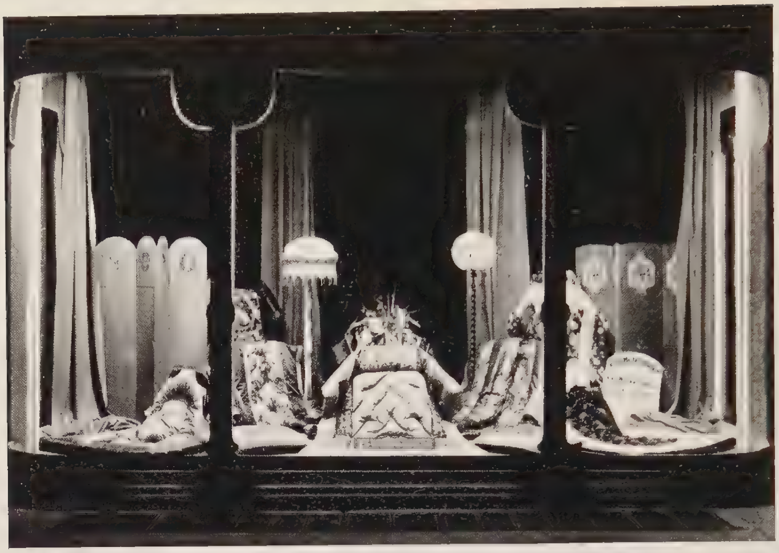


FIG. 54.—NOTE HOW CLEARLY EVERY DETAIL IN THE DISPLAY IS SEEN.

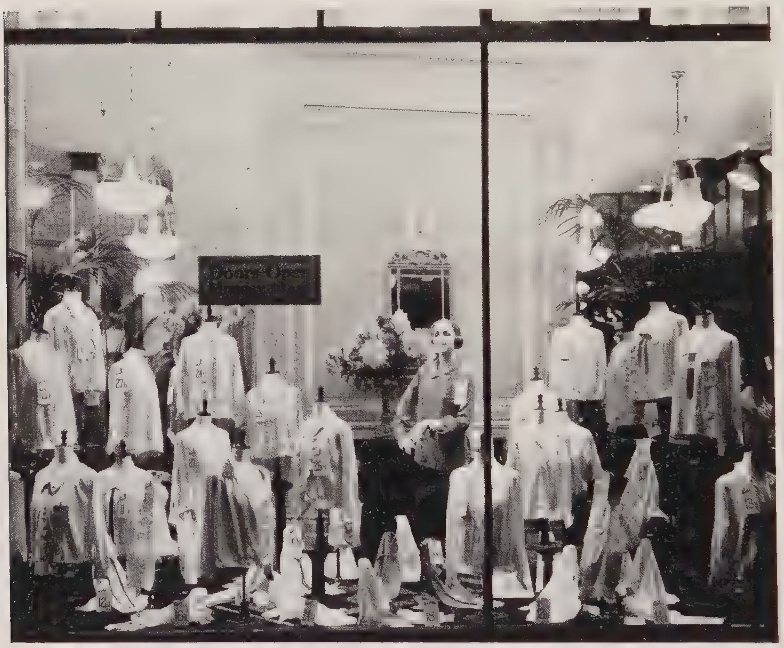


FIG. 55.—MESSRS. CANDA LTD., OXFORD STREET. THE FIRST INSTALLATION IN THIS COUNTRY OF 500-WATT LAMPS IN SINGLE-PIECE REFLECTORS.

in the flexible system of lighting, 40-, 60-, and 100-watt gas-filled lamps are generally used, but for fixed lighting 500-watt lamps are installed.

In Fig. 55 is illustrated a show window in the premises of Messrs. Canda Ltd., the well-known outfitters of Oxford Street, London. This window is illuminated by single-piece reflectors each accommodating a 500-watt gas-filled lamp ; this is the first installation in this country where 500-watt lamps were used in single-piece reflectors for shop-window illumination. Practically the whole of the illumination in the window is provided with these units ; the semi-indirect fittings which can be seen in the illustration were installed merely for decorative purposes. Attention is drawn to the left side of the illustration, where some of the reflectors are seen actually facing the observer. This speaks volumes for the efficiency in the design of the modern reflector, from the fact that the light can be controlled to such an exceptional degree.

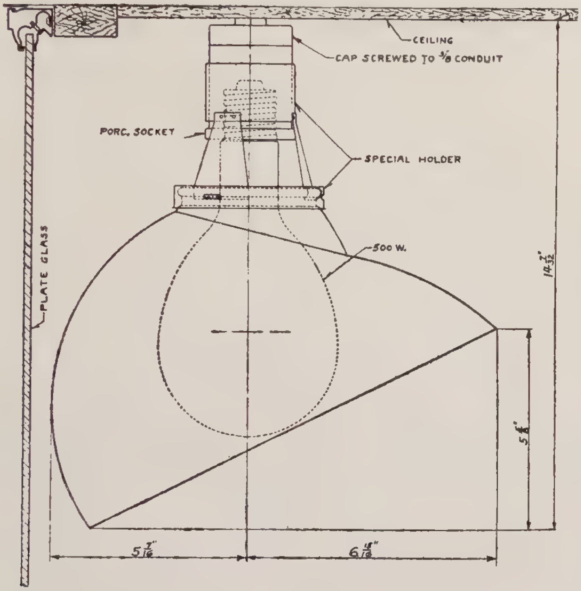


FIG. 56.—A SINGLE-PIECE REFLECTOR ACCOMMODATING A 500-WATT GAS-FILLED LAMP.

Units of this type are particularly adapted to high, large windows ; in windows of this nature 500-watt lamps are essential, because the desired intensity of illumination is between 200 and 300 foot-candles. When less foot-candles are required, smaller reflectors are better suited for the purpose.

As a striking contrast to this type of reflector, Fig. 57 illustrates a shop window in the premises of Messrs. Gamage Ltd., the well-known sports outfitters of Holborn, London ; in this window is installed a large number of very small reflectors. It will be seen that the latter are recessed into the ceiling.

A large number of unusual factors had to be taken into consideration when this installation was designed; this is because the window is very shallow, and, being an island window, the goods were viewed from all four sides. A pelmet, here, would not have assisted in the slightest degree, because hiding the back of the reflectors would not have prevented the light sources from being almost in the line of vision of persons viewing the goods. It may be mentioned here that in some installations, especially in those where reflectors are fitted in a front and two side windows, a deep pelmet in the front of the window will effectively obscure the side light sources.

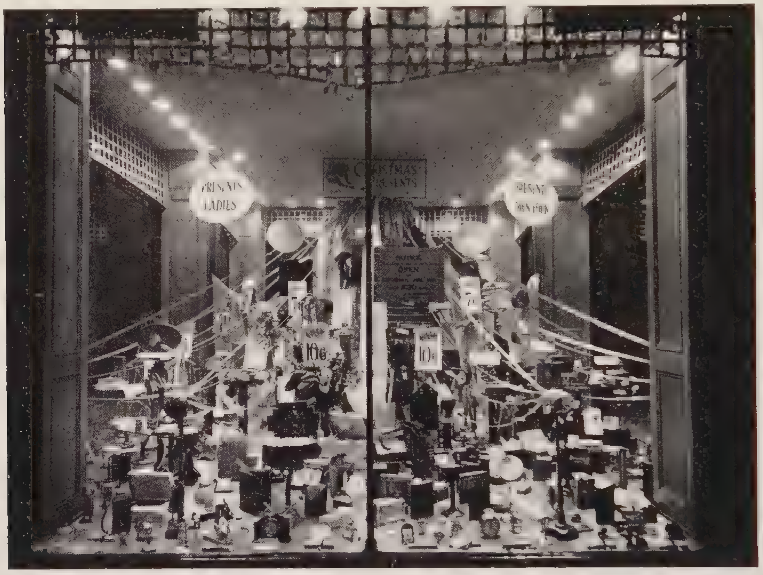


FIG. 57.—MESSRS. GAMAGE LTD., HOLBORN. A SPECIALLY DESIGNED INSTALLATION.

The only method of evenly illuminating this window with light of a high intensity was to fit the special type of reflector shown in the illustration; the reflectors were recessed in the ceiling, and spaced so that, in addition to even illumination in the window, a certain quantity of light was projected through the windows at the back and sides, so that the passages between windows were illuminated. A remarkable feature in connection with this installation is that not a single lamp filament can be seen; a glance at the photograph will show that, of the units furthest away from the observer, all that can be seen is a white line.

Distribution of Light

The distribution of light in a shop window is determined by the type of reflector fitted; the intensity of illumination depends upon the type of reflector, candle-power of lamps, and the height and depth of the window and spacing of reflectors.

In Fig. 58 are illustrated two diagrams which show the intensity of illumination in two windows respectively; in one window the height is approximately twice the depth, in the other the height is one and one-third times the depth. In the first window the spacing of the reflectors is 18 inches apart, and in the second window the spacing is 24 inches. It will be seen that each window is equipped with a different type of reflector, but in both cases 100-watt gas-filled lamps are used.

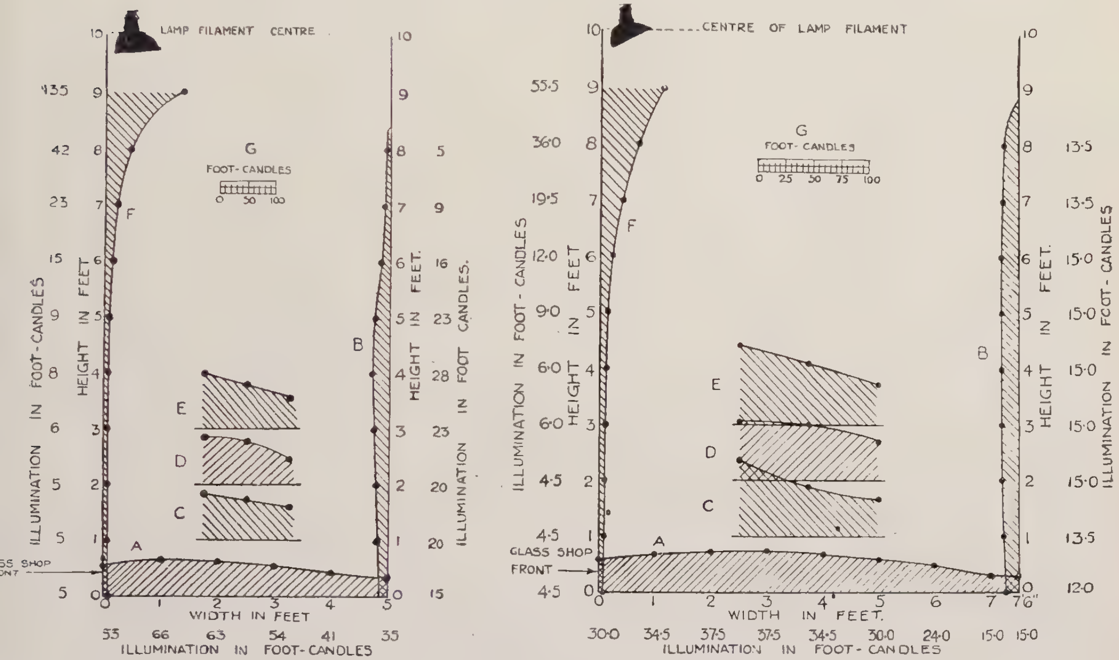


Fig. 58.

The illumination on the floor of the windows, at the distances shown from the glass, is given at the bottom of the diagram; intermediate values can be obtained by measuring the height of the shaded portion of the diagram marked A to the foot-candle scale G. Similarly the illumination at the back of the windows at various heights is given on the right-hand side of the diagrams, and intermediate values can be obtained by measuring the width of the shaded portion B. The three smaller shaded sections marked C, D, and E enable the intensity of illumination on goods placed in the centre of the window at heights of 1, 2, and 3 feet, or upon shelves similarly placed, to be ascertained. In each case the height of the shaded curve must be measured against the foot-candle scale G.

The actual illumination upon the glass of the windows is ascertained by the thickness of the shaded portion F on the left-hand side of the curves. In the installations illustrated it will be seen that to a height of 7 feet above floor-level the illumination on the glass, consequently the amount of light which is directed outside the window, is negligible.

Polar Curves

A number of reflectors with their polar curves are illustrated in Figs. 59 to 62. These illustrations are valuable from the fact that the reflectors are drawn to scale and the curves from them show the actual candle-power values.

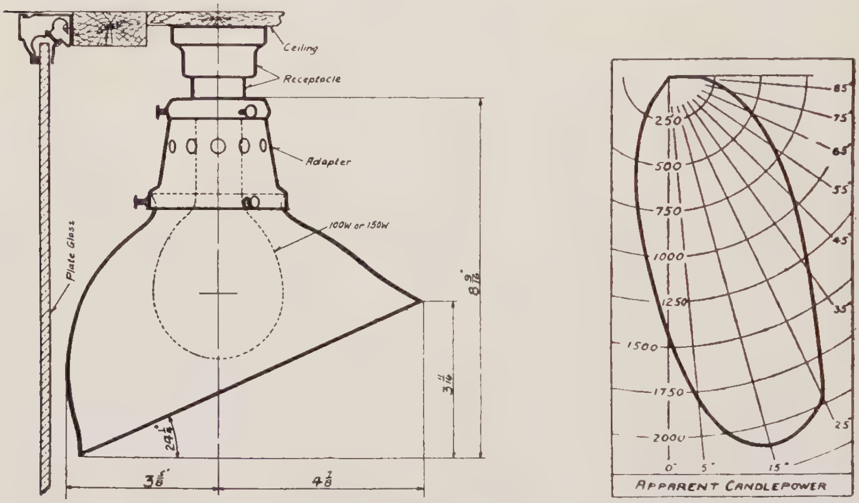


Fig. 59.

The reflector illustrated in Fig. 59 is a very popular type, and is in extensive use ; it is suitable for the average window with a depth of one-half to three-quarters its height ; the light flux covers from 0 to 90 degrees.

A totally different type of reflector is illustrated in Fig. 60. In this type it will be seen that the angle from the horizontal is only $3\frac{3}{4}$ degrees, as compared with $24\frac{1}{4}$ degrees in the previous one illustrated. $3\frac{3}{4}$ degrees does not appear to be a large quantity ; in actual light distribution it is an important factor, and it has been found that, where errors in fixing have accounted for less than $3\frac{3}{4}$ degrees deviation from the correct position, the installation has been comparatively inefficient.

With regard to candle-power values, from the reflector illustrated in Fig. 59 the maximum candle-power is 2100, and this is at an angle of 15 degrees only ; in the reflector illustrated in Fig. 60 the maximum candle-power is reached at the 5-degree point, and this, 2650 candle-power, is maintained from 5 to 10 degrees. This reflector is suitable for high, shallow windows, with medium high displays, island windows, or windows which have the upper part of the background of glass ; it

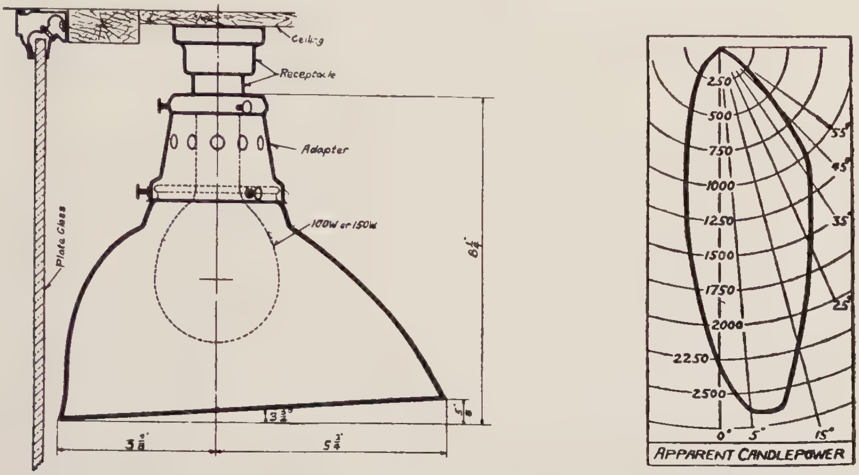


Fig. 60.

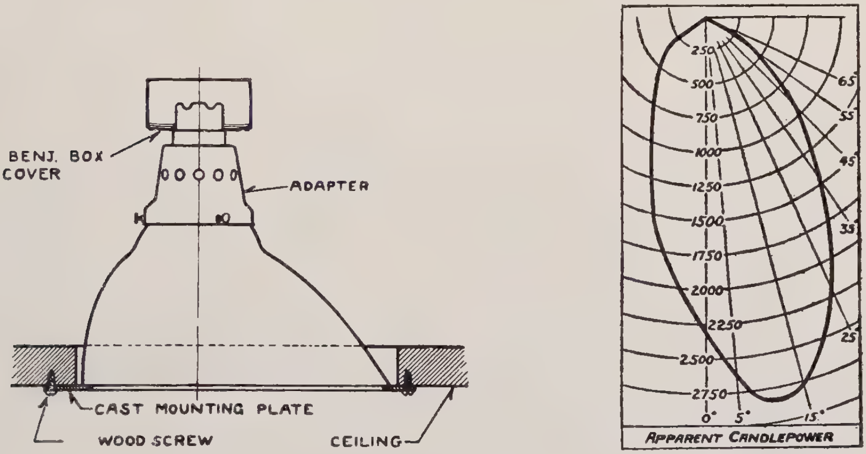


Fig. 61.

is of the concentrating type, and cuts the light off very sharply on the 55-degree line.

A very similar reflector is illustrated in Fig. 61. It will be seen that, in its normal position, the base of this reflector is perfectly horizontal; this feature obviates the necessity for fitting the reflector inside the window behind the usual pelmet; the function of the pelmet is partly decorative and partly to hide reflectors and light sources. This reflector was designed specially for installation in windows where it is desired that all reflectors shall be obscured. Since it is perfectly horizontal, it will be seen that it is installed with its bottom exactly flush with the ceiling. It is adapted for high, shallow windows, with a medium high display, windows without background, or windows with the upper part of the background of glass; it is of the concentrating type, with an angle of cut-off on the 55-degree line.

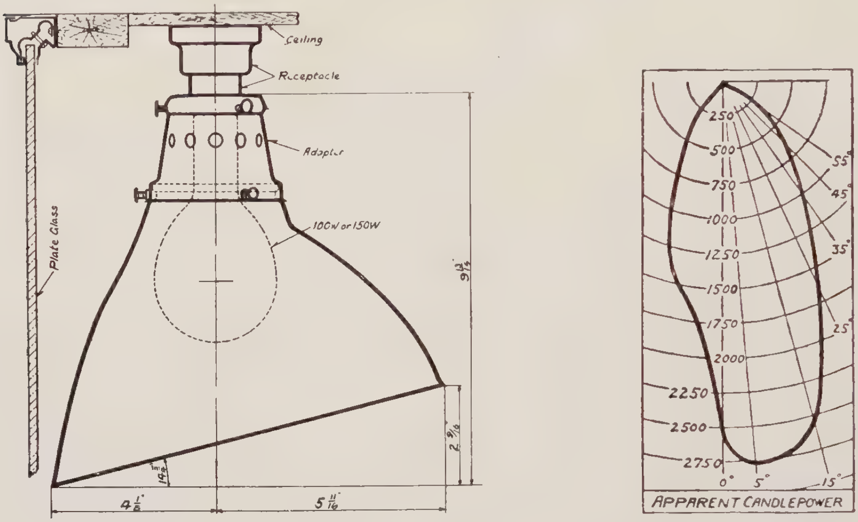


Fig. 62.

A different type of reflector, but one which produces a similar polar curve, is illustrated in Fig. 62. The difference in the contour of the reflector has the effect of reducing the intensity of illumination on the left of the curve, the result being to maintain the maximum candle-power from 3 to 12 degrees. This reflector is very suitable for high, shallow windows, with a medium low display, for island windows, or windows with the upper part of the background of glass; it will be seen that, here again, the angle of cut-off is on the 55-degree line.

Experimental Curves

In Fig. 63 are illustrated two halves of a polar curve taken from the same reflector equipped with lamps of different candle-power. It will be seen that the ratio between candle-power and light output is not the same for both lamps, this showing to a very marked degree that each type of reflector should be used with the lamp best suited to it. The reason for the difference in these curves is that filament centres vary in height and width in various types of lamps; this difference in the position of the filament, relative to the planes of the reflecting surfaces, considerably alters the shape of the polar curve, and, therefore, the intensity of illumination upon goods displayed. It should be mentioned that we have known cases where an installation of excellent reflectors has been very inefficient merely because unsuitable lamps have been fitted in them.

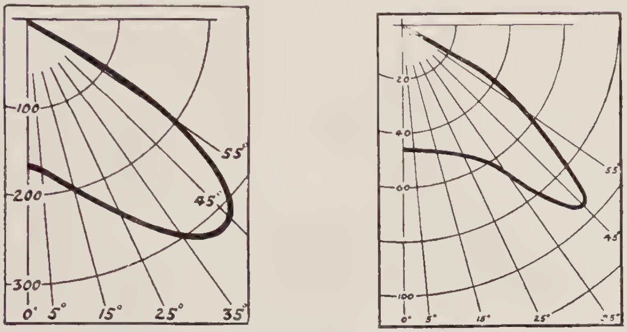
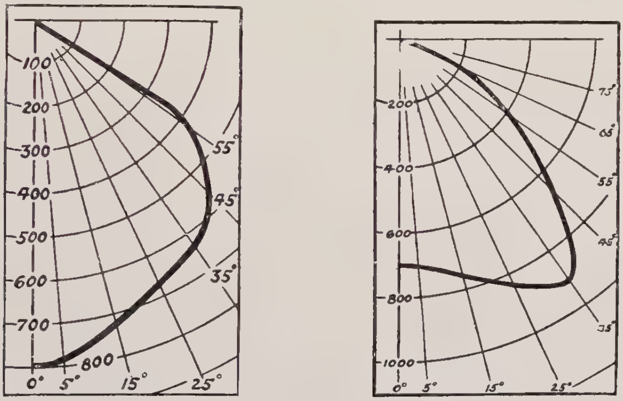


Fig. 63.



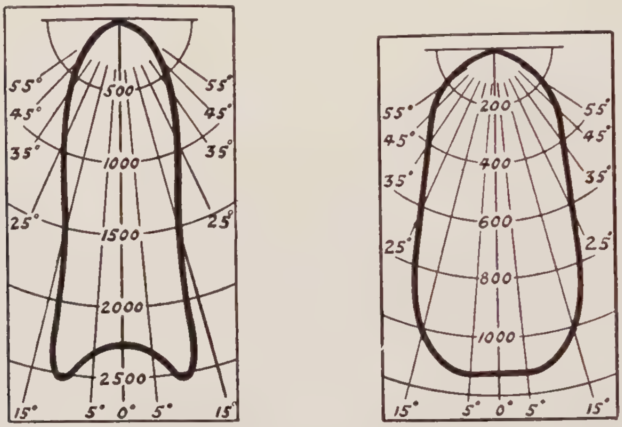
A

B

Fig. 64.

The two curves, A and B, Fig. 64, are interesting not only for the broad distribution of light, but from the fact that the maximum candle-power is obtained through a wide angle variation. At A, the angle of cut-off is 55 degrees as compared with 65 degrees at B; at 45 degrees the candle-power is the same as at B, *i.e.* 600. From this point the two curves are very dissimilar, the candle-power of A increasing until the maximum intensity, 800, is reached at a point immediately under the reflector. At B, the maximum intensity is reached on the 35-degree line, from which point it gradually decreases until, immediately under the reflector, 700 candle-power is reached. From a consideration of these curves it will be seen that these reflectors have been designed to meet special requirements, and that they would be useless if used for other purposes.

The curves, A and B, illustrated in Fig. 65, are the result of experiments we have carried out with a special type of reflector in order to determine the ratio between intensity, distribution, and various-wattage lamps: the wattage of the lamp which produced the curve at A was twice the wattage at B; the lamp filament at A was half an inch higher in the reflector than the lamp at B.



A

B

Fig. 65.

Regarding A, it will be seen that the beam at its narrowest point is 15 degrees each side of the centre, and the maximum intensity, 2500, is obtained at $7\frac{1}{2}$ degrees; the intensity at the centre decreases to 2250. At B, the beam spread is greater and the narrowest portion is 25 degrees each side the vertical; the maximum intensity, 1130, is immediately under the centre of the reflector, and this is maintained for 8 degrees each side the centre. From consideration of these curves it would appear that B is the more efficient, although there are errors in filament position relative to the position of the filament at A. These are the most divergent results which we could obtain after tests with various types of lamps in a special reflector. From these results it would appear that the lamp at B is best suited to this reflector ; we would point out, however, that it is possible that the reflector was designed for an entirely different lamp.

Before proceeding with the design of shop-window installations we would point out that the previous illustrations show the exact positions of lamps and reflectors to produce the polar curves as shown. Any deviation from these positions will result in distorted distribution of light.

INSTALLATION DESIGN

When an installation is designed the whole of the factors regarding light control should receive adequate consideration. A suitable type of reflector is the first essential ; height and spacing are other factors. An installation can be efficient, but it can also be wasteful if the intensity of light in the windows cannot be controlled. The efficient installation, then, is one in which the switching arrangements are such as to enable the windows to be illuminated with various intensities of light.

For instance, a display window is always more or less bright according to the nature and colour of the goods displayed, and the colour of the background. Dark goods are displayed on a light background, and a dark background is suitable for the display of white and some classes of coloured goods. Sometimes a window will display a combination of light and dark goods. In the display of such a combination the background must not be too light or too dark, or the goods cannot be seen to the best advantage. Here, especially at points where the dark goods are displayed, it will be found to be advantageous to illuminate the windows with light of low intensity ; this will make just the difference between goods appearing flat, or as the display man intends them to be seen.

Again, on dark and dull days it is very difficult to discriminate between qualities when viewing dark or light goods under decreased daylight intensities. It is therefore necessary, on such days, to illuminate the goods with artificial light of suitable intensity. For this purpose the units in the installation should be connected to a number of circuits one or more of which may be switched in as desired.

The installation illustrated in Fig. 66 is composed of a number of circuits under independent and combined control ; the installation comprises a number of reflectors of different types fitted in three rows. In the bottom row twenty-two units consisting of reflectors equipped with 150-watt lamps are wired alternately on two circuits. In the centre row twenty-one reflectors equipped with 200-watt lamps are situated immediately in front of the bottom row ; these also are on two circuits. The third row consists of eight window-spots wired individually. It should be noted that the back end of the reflectors in the second row is actually in line with the front of the units in the first row; a consideration of the polar curves of these units will serve to show that the installation could not be efficient if they were otherwise placed.

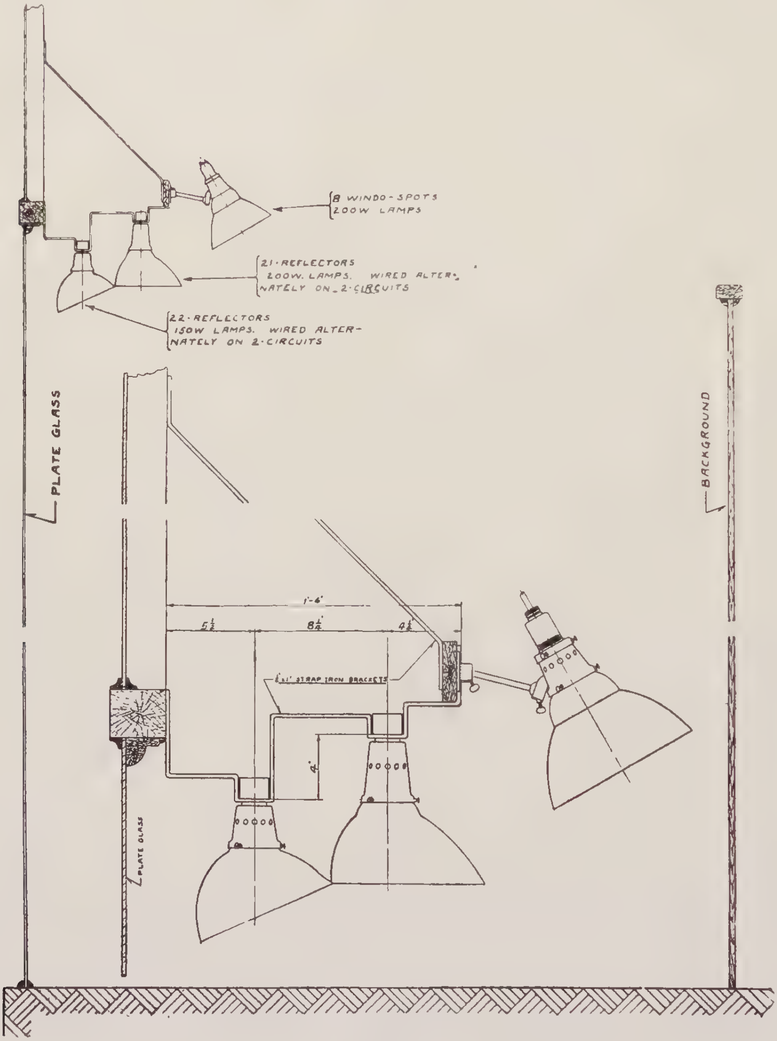

8 WINDO-SPOTS
200W LAMPS
21·REFLECTORS
200W. LAMPS. WIRED ALTERNATELY ON 2·CIRCUITS
22·REFLECTORS
150W LAMPS. WIRED ALTERNATELY ON 2·CIRCUITS
PLATE GLASS
BACKGROUND
1'-6"
5½
8¼"
4¼"
¼"x1" STRAP IRON BRACKETS
4"
PLATE GLASS

FIG. 66.

At the bottom of the illustration, where the position of the units is shown in greater detail, and where actual dimensions are given, it will be seen that even slight alterations in the position of the reflectors must result in uneven illumination. Let us assume, for instance,

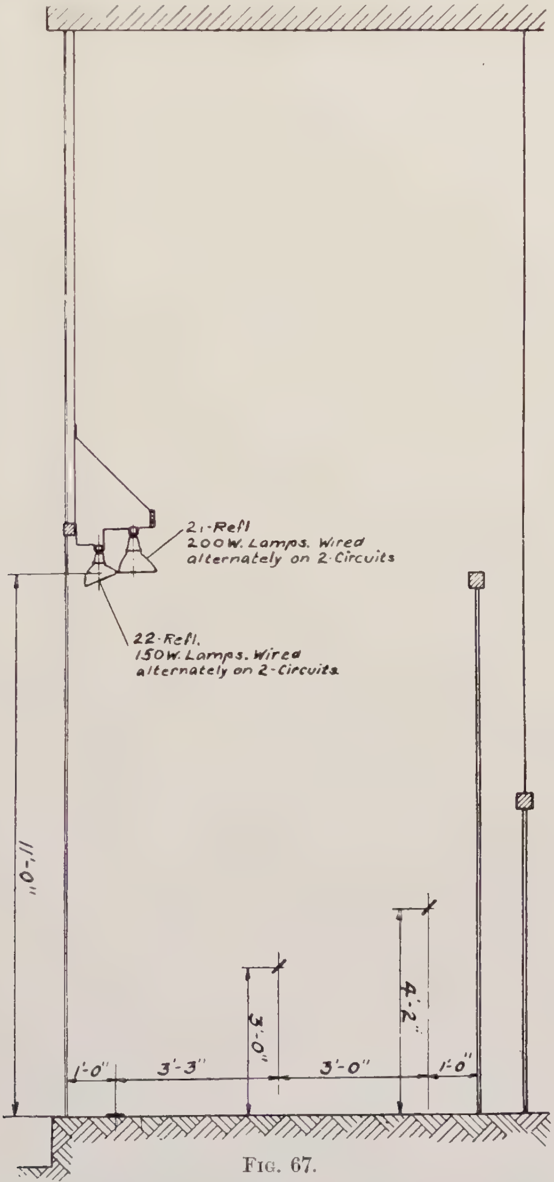


Fig. 67.

that instead of the centres being $8\frac{1}{4}$ inches apart the distance is increased to 12 inches. This difference of barely 4 inches does not appear to be very great, but it would considerably affect the distribution of light. The extent of this variation can be seen by the reader himself if, on a sheet of paper, he constructs the reflectors with their polar curves: (*a*) with the reflectors in their correct position; (*b*) with the reflectors out of position to a distance which corresponds to approximately 4 inches.

When this installation was tested the following results were obtained:—

One circuit	52 foot-candles.
Two circuits	105 ,,
Three circuits	181 ,,
Four circuits	245 ,,

These figures represent the average illumination without the window-floods; with the latter on, the average intensity would be increased at least 10 per cent.

Another installation, illustrated in section and plan, is shown in Fig. 67. This installation comprises two rows of units of different types: in the top row the reflectors are equipped with 200-watt lamps, and in the bottom row with 150-watt lamps; the top and bottom rows contain twenty-one and twenty-two reflectors respectively. In each row the units are wired alternately on two circuits, making four circuits in all.

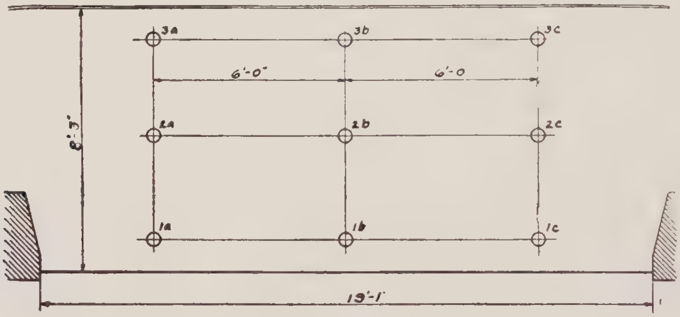


Fig. 68.

From the sectional illustration it will be seen that the height from the bottom of the window to the centre of the light source is 11 feet; the distance between light-source centres can be calculated from the previous design. Attention is drawn to the height and depth dimensions shown at the bottom of the window, because these are the positions from which readings were observed when tests were carried out.

The plan, Fig. 68, shows that the floor has been divided into three lines, 1, 2, and 3 respectively; each line has also been divided into three parts, *a*, *b*, and *c*, making nine positions in all. The actual and average foot-candles of illumination at 1*a*, 1*b*, 1*c*, etc., with the watts expenditure for various combinations, is shown in Table VI. Various circuit combinations, with watts expenditure per combination and watts per foot based on 20 feet, and the average foot-candles, are given in Table VII.

TABLE VI

FOOT-CANDLE READINGS

Stations	Circuits on			
	1 or 2	1 and 2	1, 2 and 4	1, 2, 3 and 4
	Watts			
	1650	3300	5500	7500
1*a*	40	99	157	210
1*b*	46	101	193	218
1*c*	43	94	154	208
1 avg.	43	98	168	212
2*a*	62	135	228	315
2*b*	80	145	257	346
2*c*	63	134	228	314
2 avg.	68	138	238	325
3*a*	40	82	128	186
3*b*	53	107	161	225
3*c*	40	80	126	186
3 avg.	44	90	138	199
Average	52	109	181	245

TABLE VII

Circuits	Watts	Watts per ft., based on 20 ft.	Avg. Ft.-C.
1 or 2	1650	82·5	52
3	2000	100·0	65
4	2200	110·0	72
1 and 2	3300	165·0	109
1 and 3	3650	182·5	118
1 and 4	3850	192·5	125
3 and 4	4200	210·0	137
1, 2 and 3	5300	265·0	174
1, 2 and 4	5500	275·0	181
2, 3 and 4	5850	292·5	190
1, 2, 3 and 4	7500	375·0	245

The application of colour to shop-window lighting gives added scope to the art of the display man, and provides him with more tools with which to work. Colour-screen equipment, such as illustrated in this section, suggests unlimited possibilities when it is remembered that every individual window display can be enhanced in beauty if the *correct colour scheme* is provided. (The reader should study the portion of this work dealing with the effect of coloured light upon coloured material.) When colour screens were first introduced for shop-window illumination the filters were made of coloured glass placed in square frames fitted at the bottom of the reflectors. A defect was quickly found in the fact that the heat from the lamp caused the glass to crack, with the result that very often goods were damaged through pieces of glass falling upon them. Another defect was the unsightliness of square frames fitted at the base of round reflectors; this is termed a defect because, in all classes of lighting, and especially in shop windows, where reflectors are likely to be seen, beauty and utility should go hand in hand.

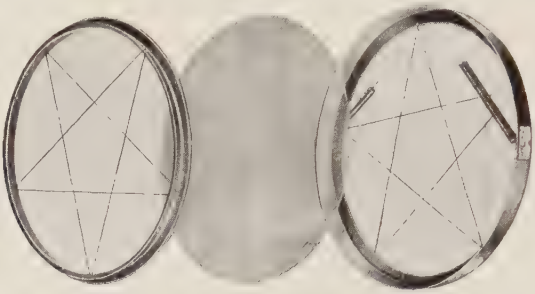


FIG. 69.—TYPICAL COLOUR SCREEN.

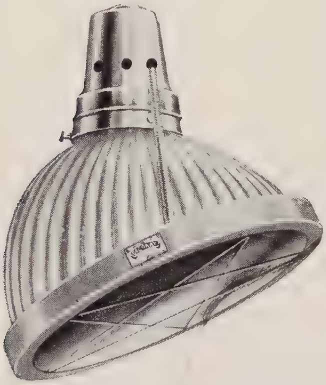


FIG. 70.—REFLECTOR FITTED WITH COLOUR SCREEN.

COLOUR SCREENS

The colour screens illustrated are extremely neat in design, and are easily fitted without removing the reflector. The colour filter, which is made of non-inflammable material, is held in position between two rings with retaining wires stretched across the openings of each. Two special springs serve to clip the attachment to the gallery. As a general rule, four filters are supplied by manufacturers with each screen, the colours being red, amber, green, and blue ; other colours to suit various-coloured displays can, of course, be obtained.

Window Floods

A window-flood unit is illustrated in Fig. 71. This unit is specially designed to throw a concentrated beam of light upon any special feature of the display, or for flooding the whole window with white or coloured light. In practice it is fixed to any flat surface, either vertical, inclined, or horizontal; no special care is required in fixing, because a ball-and-socket joint gives universal adjustment to the direction of the beam.

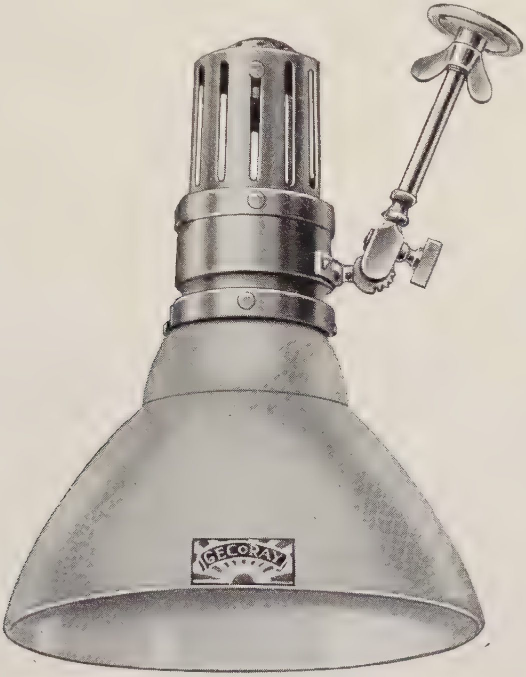


Fig. 71.—A Window Flood.

Spot-Lights

A spot-light, an essential for window-lighting effects, is illustrated in Fig. 72. This type of unit is solidly constructed, with a metal housing, and it is amply ventilated. It is fitted with a high-grade lens, and the beam is adjusted by a telescopic arrangement. The bracket upon which the unit is fitted allows a concentrated beam of light to be directed exactly where it is required. As a general rule colour screens are supplied by manufacturers. The latest development in this direction is a multi-coloured screen, which is operated with a motor; the latter is synchronized with the controller, so that a different-coloured filter is presented to the lens each time a change of effects takes place.

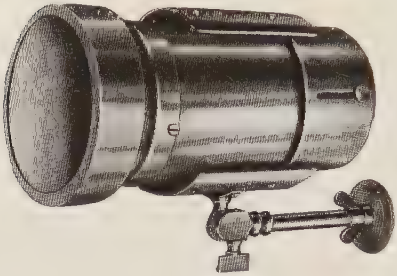


Fig. 72.—A Spot-Light.

The chief object of a good window display, and the installation of spectacular lighting effects, is to draw attention to the business premises. It is considered that a person attracted to a shop window is at least 80 per cent. of a sale; that is, of a hundred persons attracted to a window, and who view the goods displayed, at least eighty become purchasers. For the completion of a sale, however, and to make purchasers desirous of visiting the premises again, it is necessary for the shop interior to be quite as attractive as the medium of attraction in the first instance—the shop window. There is no better method

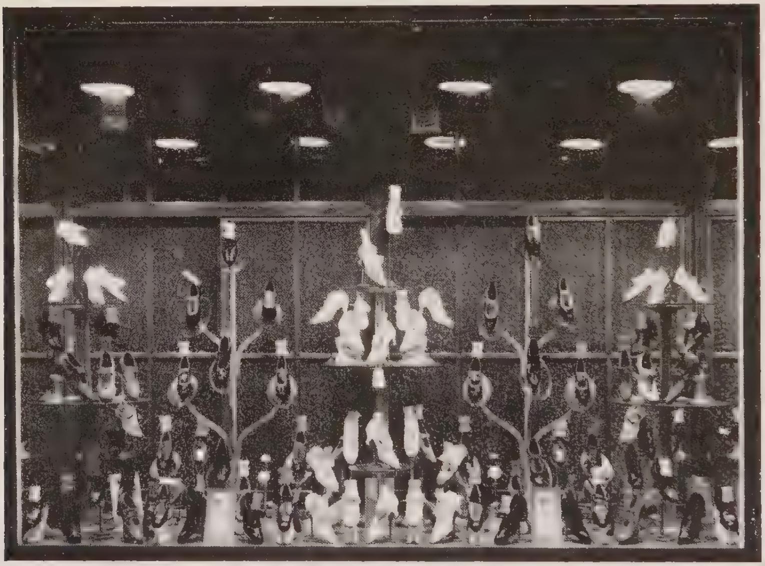


Fig. 73.—Indifferent Lighting. A Pelmet to conceal the Units would improve the Effect.

of making the interior of any business premises attractive than by the installation of the correct type of lighting equipment.

The design and construction of lighting equipment has been so progressive that there is a large variety of fittings on the market. These can be divided into five classes, the latter being governed by the way in which the units control and diffuse the light. A large number of shop interiors are illuminated with 10-inch and 12-inch opal shades and bare gas-filled lamps; these are not included in the principles which govern good illumination. The five classes mentioned above are :—

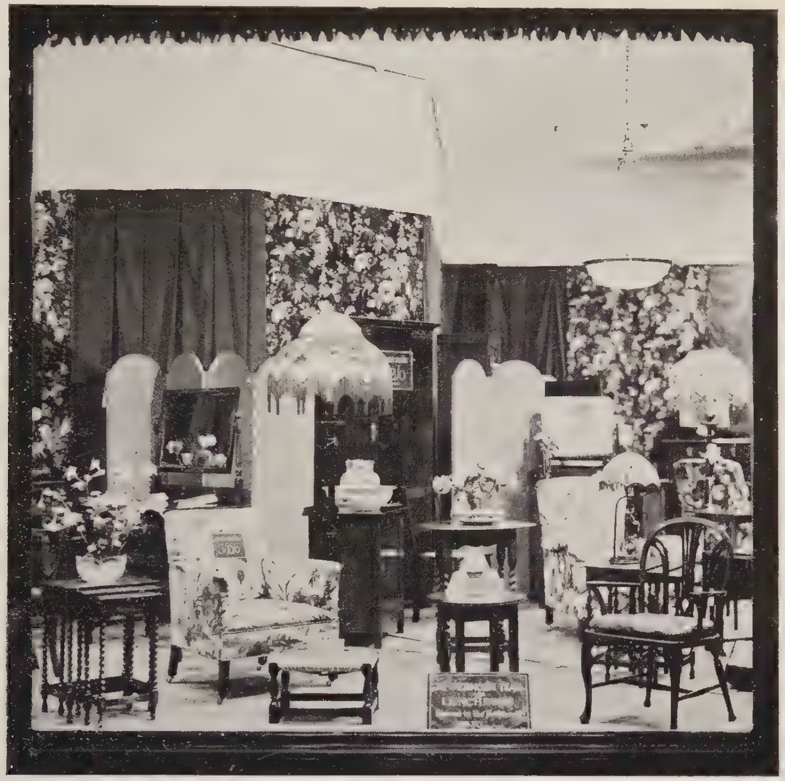


FIG. 74.—ONE OF THE BEST ILLUMINATED WINDOWS IN LONDON.
MESSRS. WARING & GILLOW.

1. Enclosing-diffusing.
2. Enclosing-directional.
3. Semi-enclosing.
4. Semi-indirect.
5. Totally indirect.

The chief factors which govern the selection of any particular unit from the many in the various classes are its efficiency, appearance, and cost. Efficiency in this case is the suitability of the unit to meet certain requirements ; that is, a unit may be efficient for one interior and quite inefficient for another. The pleasing appearance of a unit is an essential of an attractive interior ; a unit should have a pleasing and decorative contour, it should not be too small or too large, and the illumination should not be too low or excessive. Regarding cost, it may be said that a slightly higher cost should not induce one to decide against units which it is known will meet every requirement. It should be remembered that satisfactory equipment, once installed, will give good service for the many years the installation will be in use.

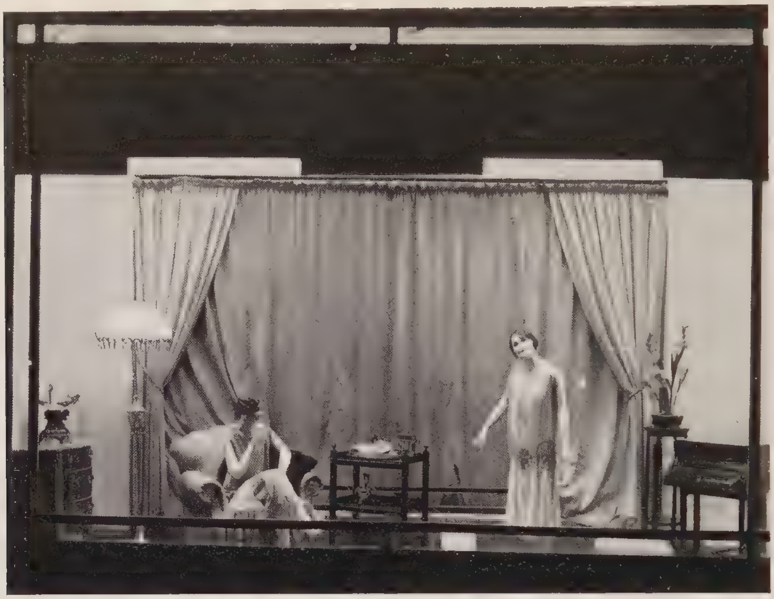


Fig. 75.—Excellent Lighting. A Show Window at the Hackney Electricity Supply Company's Showroom.

Details of the classes of units mentioned are :—

Enclosing-diffusing.—This type of unit is illustrated at 15 and 18 in Table XI. These units are used extensively, especially since the introduction of the gas-filled lamp. They may be obtained in a large variety of shapes and designs, which will prove to be suitable for all classes of shop interiors. With these units the light is distributed throughout the interior in all directions, and not in a downward direction towards the counter ; they make a shop interior bright and attractive, and provide adequate illumination for high shelves and wall cases.

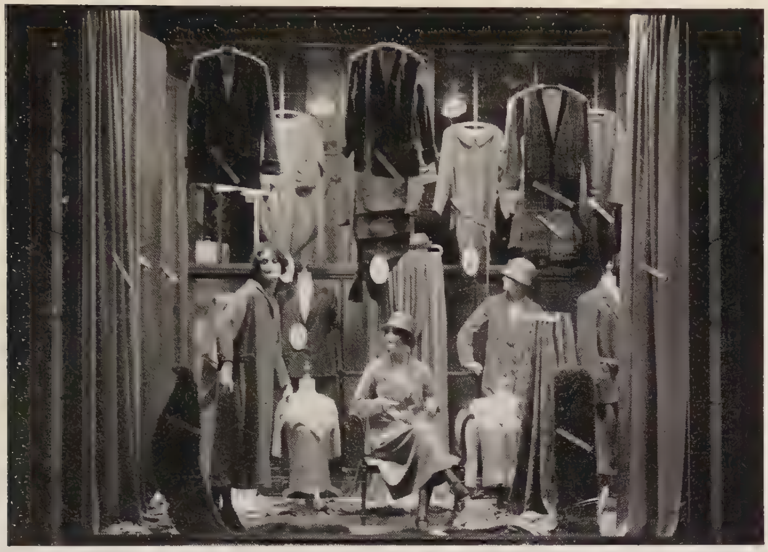


FIG. 76.—BAD LIGHTING. NOTE THE HALO ROUND THE GOODS, CAUSED THROUGH THE REFLECTIONS OF THE LIGHTING UNITS.

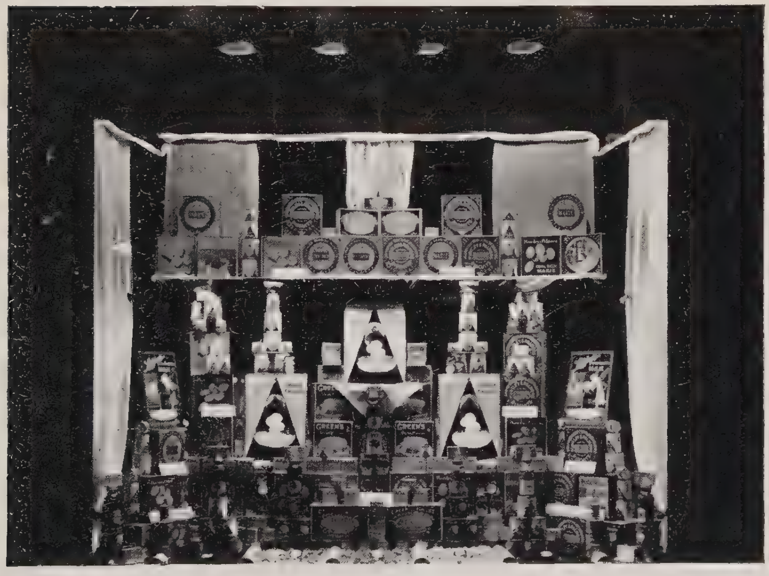


FIG. 77.—A PELMET IS REQUIRED IN THIS WINDOW.

Enclosing-directional.—This type of unit is illustrated at 16 and 18 in Table XV. As the name implies, this unit is totally enclosed and is capable of directing the light; the latter is in a downward direction, so that, compared with enclosing-diffusing units, there is less illumination upon the upper portions of an interior and more upon the floors. The maintenance schedule must be rigidly adhered to where these units are installed, because, especially in interiors with a fairly high reflection factor, the dust which would settle on the top of the units would absorb a certain proportion of the light.

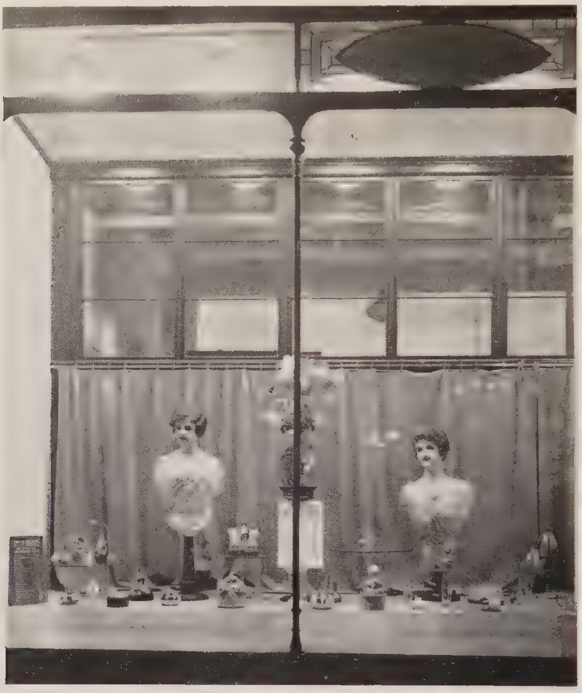


Fig. 78.—These Reflectors are not suited to this Type of Window. Note the Glare.

Semi-enclosing.—This type of unit is illustrated at 20 in Table XV. It is suitable for fitting near the ceiling or for suspending at some distance from the ceiling. When fitted at a suitable height and spacing ratio it will be found that the illumination is abundant and well diffused; the quantity of illumination depends, of course, upon the correct type of lamps being used. This unit is very suitable for light interiors such as refreshment rooms, etc.

Semi-indirect.—These units are illustrated at 22 and 24 in Table XV. They are very suitable in interiors where the ceilings and upper portions

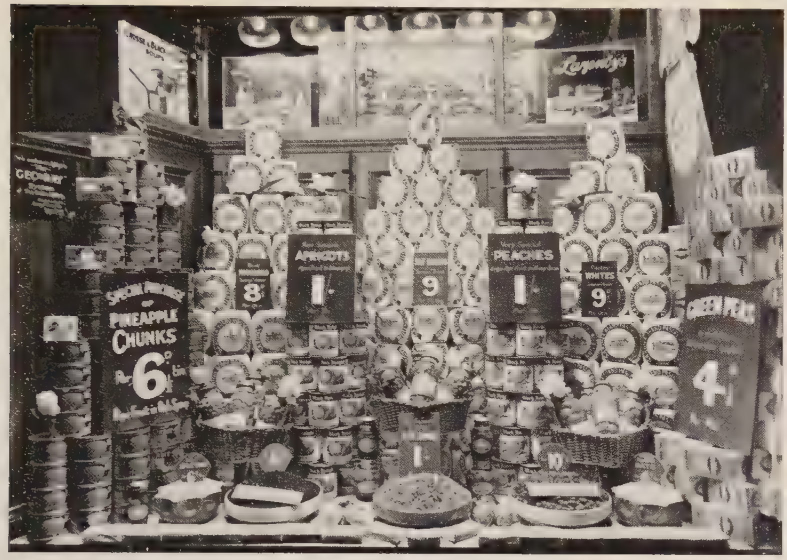


Fig. 79.—The Goods are perfectly illuminated, but the Reflections should have been avoided.

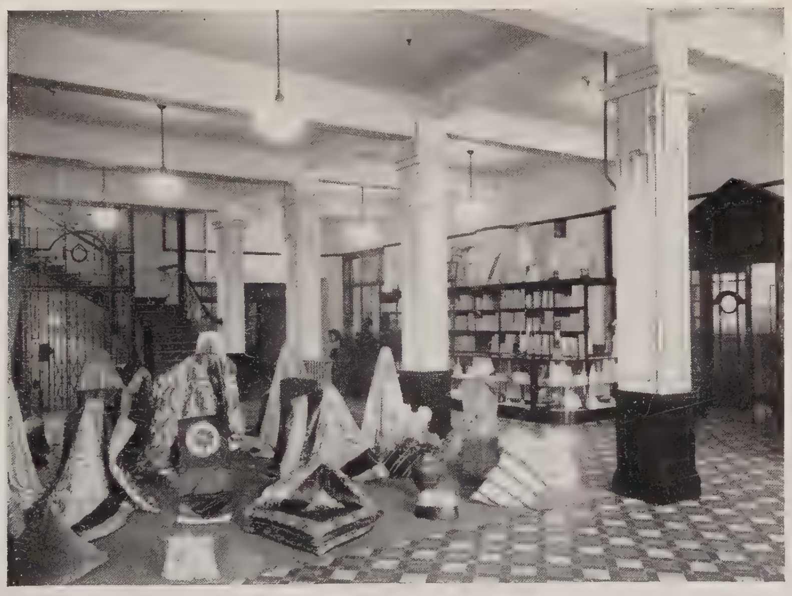


Fig. 80.—A Good Example of Store Lighting.

of the walls are finished in light colours which have a good reflection factor. A portion of the light is directed through the opal glass or alabaster in a downward direction, and the remainder is reflected in an upward direction towards the ceiling; from here it is reflected partly downwards and partly to the walls, thus ensuring that the light is well diffused.

Totally indirect.—A totally indirect unit is illustrated at 28 in Table XV. This type of unit is designed to meet special requirements; it is suitable where it is necessary to have a quiet and subdued atmosphere. The whole of the light from these units is reflected from walls and ceilings, and is thus perfectly diffused and soft and free from shadows.

The Reflection Factors of Coloured Surfaces.—Mention has been made of the necessity for walls and ceilings having high reflection factors in order to minimize the absorption of light. The following table shows the proportion of light which is reflected from coloured surfaces:—

TABLE VIII

Colour	%	Colour	%	Colour	%	Colour	%
White paper	84	Ivory white	77	Buff stone	37	Forest green	16
Grey	70	Caen stone	68	Buff	60	Olive green	21
,,	69	Ivory	73	Pale azure	37	Pale azure	52
,,	55	Ivory tan	56	Tan	28	,, ,,	39
,,	42	Primrose	70	Cocoanut brown	16	Sky blue	36
,,	39	Lichen grey	69	Satin green	63	Shell pink	51
,,	28	Pearl grey	73	Bright sage	38	Pink	50
,,	20	Silver grey	51	Ivory tan	43	Cardinal red	16

In this table it will be seen that various degrees of grey vary in their reflection factor from 20 to 70 per cent.; pale azure also varies considerably.

In the design of an installation for a shop interior the location of the lighting points should receive adequate consideration. This is necessary not only from an efficiency point of view, but from the fact that, if the units are wrongly spaced and it becomes necessary to alter their location, a considerable expense will be involved in alterations to wiring, etc. The installations illustrated in the following pages have been designed to give approximately uniform illumination, although it must be said that no hard-and-fast rule can be given to govern maximum foot-candle intensities.

Let us consider, for instance, the lighting of a hardware store. The intensity of illumination for interior lighting will depend upon the location of the premises. If the latter are situated off the main road, where the intensity of street illumination is very low, an intensity as low as 4 foot-candles will be sufficient. If the same stores, however, are situated in a main thoroughfare, where the intensity of illumination due to street lighting is fairly high, an intensity of 4 foot-candles would be too low and the interior of the shop will appear dull. Under these conditions it may be necessary to instal units to produce an intensity of at least 8 foot-candles.

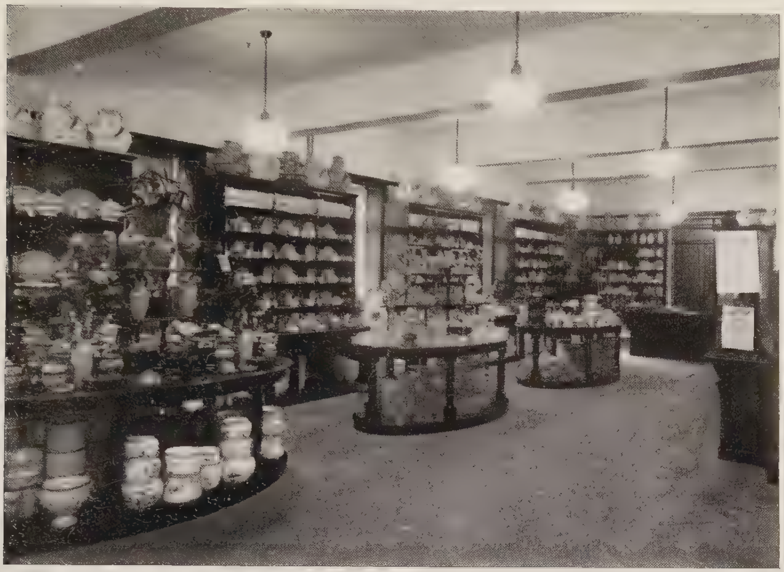


FIG. 81.—NOTE THE SOFT SHADOWS.

LIGHT INTENSITIES FOR STORES

Generally speaking, an intensity of 12 foot-candles will meet the requirements of the majority of shops and stores, although this value may be increased or decreased according to position of the premises. As a guide to the necessary amount of illumination in various shops and stores we submit the following:—

2-3 *Foot-candles.*

This is adequate for general illumination in restaurants, buffets, etc., where the general lighting is supplemented by decorative lighting units such as table lamps or candle brackets, etc. The effect of these decorative features would be lost if the general intensity of light were too high.

4-6 *Foot-candles.*

This will provide adequate illumination for almost all interiors of business premises situated in small towns or suburban districts.

6-10 *Foot-candles.*

This intensity is necessary in the main thoroughfares of small towns where the intensity of street lighting is high. Interiors situated in well-illuminated market squares should be illuminated to this intensity by virtue of higher intensities of light on market days than on ordinary days.

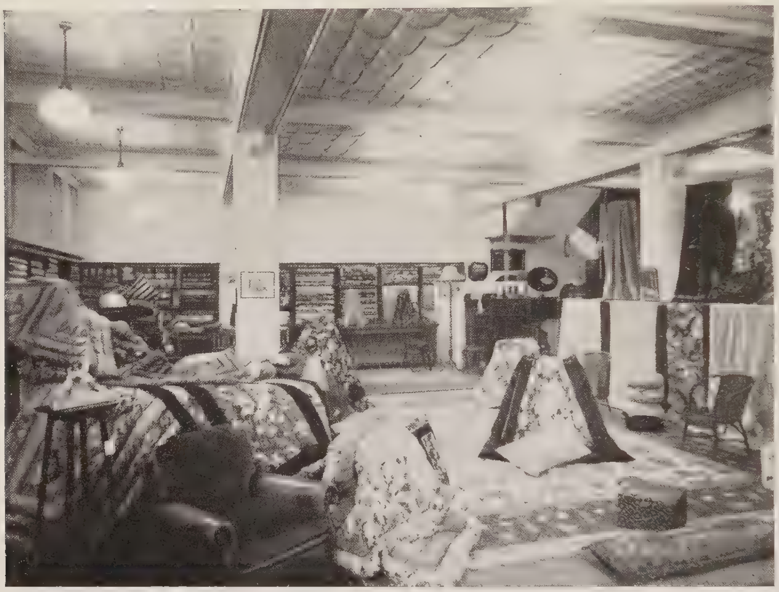


Fig. 82.—A Difficult Subject well treated.

10-15 *Foot-candles.*

This is brilliant lighting. It is most desirable for high-class interiors where fine goods such as art china, silver, and lace are displayed; this intensity is also suitable for interiors or departments where semi-dark goods are displayed.

15-20 *Foot-candles.*

This is suitable for underground stores where interior illumination is not supplemented by window lighting or street lighting. Very dark goods and browns will show to advantage under this intensity of light.

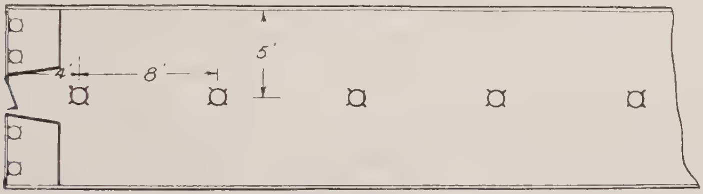
Regarding the design of installations for interiors, it is evident that, providing the right type of unit and lamp have been selected, even illumination depends upon the height and spacing of units. All departments in shops and stores are laid out in a symmetrical manner, so that they can be theoretically divided into squares. If the units are placed in these squares, even illumination will be obtained. In some interiors, especially in the corners, counters are rounded and a great deal of space is occupied by displayed goods; here slight alterations to the spacing will be necessary, but, knowing the height of the units, calculations can be made and the correct location of units determined. In many stores the ceilings are divided into squares architecturally (an example is illustrated in Fig. 82); here it is merely a matter of deciding upon the correct type of unit for the given height and spacing.

LIGHTING DESIGNS FOR STORES

Design 1.

This interior is long and narrow, and the obvious position for the lighting units is down the centre. Although the width of the premises is 10 feet, a correct spacing ratio, as applied to much larger interiors, is not suitable in this case owing to restricted ceiling height. Using 200-watt lamps in units not less than 7 feet above the floor, the average foot-candles, with ceilings of various reflection factors, are shown in the table. The first unit is situated at a distance of 4 feet from the front

FIG. 83.—DESIGN 1.



Mounting Height of Enclosing Units—Not less than 7 ft. above floor

Suspension Distance to Top of Bowl Units—1½ to 2 ft.

Approximate Average Foot-Candles Using 200-watt Gasfilled Lamps

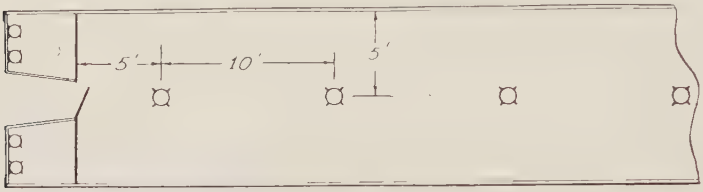
Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	9½	8	7	5½
Enclosing—Light Directing, or Semi-Enclosing	11	9½	8½	7½
Semi-Indirect or Totally Indirect	8½	7	6	—

of the shop, and the remaining units follow at 8-feet centres. The intensities shown are calculated from a ceiling height of 10 feet.

Design 2.

This is for an interior having a width of 10 feet but a height of 12 feet. A correct spacing ratio is adopted here ; that is the distance between units, and the wall is half the distance between units. The foot-candle intensities are shown as before.

Fig. 84.—Design 2.



Mounting Height of Enclosing Units—Not less than 9 ft. above floor

Suspension Distance to Top of Bowl Units—1½ to 2½ ft.

Approximate Average Foot-Candles Using 200-watt Gasfilled Lamps

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	7	5½	5	3½
Enclosing—Light Directing, or Semi-Enclosing	8	7	6½	5½
Semi-Indirect or Totally Indirect	6	5	4	—

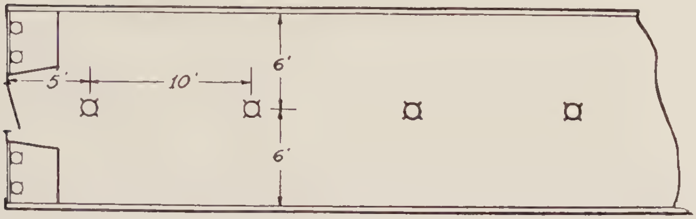
Design 3.

In this design is illustrated the same type of interior, but it is slightly wider, being in this case 12 feet ; the ceiling height is, as with design 2, 12 feet. Here, it is obvious that the candle-power of the units must be increased. The next suitable size is 300 watts, and this has the effect of considerably increasing the average foot-candle intensities as shown in the table.

Design 4.

With increased ceiling heights and greater widths, with the same spacing the intensity must decrease ; this is shown in this design. The spacing between units is 10 feet and the width is 15 feet ; with a ceiling height of 14 feet and the same spacing as in design 3, the intensities are much lower for the same wattage lamps. The table gives the approximate foot-candles.

FIG. 85.—DESIGN 3.



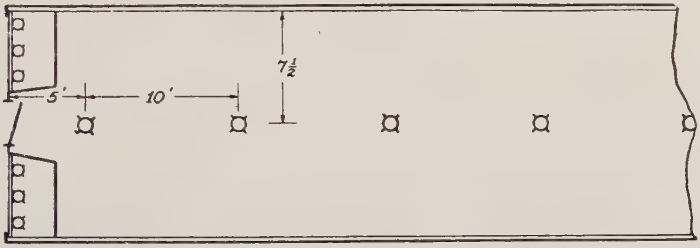
Mounting Height of Enclosing Units—Not less than 9 ft above floor

Suspension Distance to Top of Bowl Units—1½ to 2½ ft

Approximate Average Foot-Candles Using 300-watt Gasfilled Lamps

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	10	8½	7	6
Enclosing—Light Directing, or Semi-Enclosing	11½	10	9	8
Semi-Indirect or Totally Indirect	9	7½	6	—

FIG. 86.—DESIGN 4.



Mounting Height of Enclosing Units—Not less than 10 ft above floor

Suspension Distance to Top of Bowl Units—1½ to 2½ ft

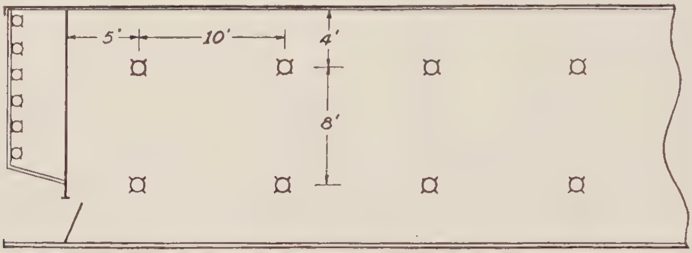
Approximate Average Foot-Candles Using 300-watt Gasfilled Lamps

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	7	6	5½	4
Enclosing—Light Directing, or Semi-Enclosing	8½	7½	7	6
Semi-Indirect or Totally Indirect	6½	5½	4½	—

Design 5.

Above a width of 15 feet with a 10-feet spacing the distribution of light becomes uneven ; this necessitates a different method of spacing altogether. Such a method is illustrated in this design. Here the width is 16 feet, height 12 feet, and the lamps used are 150 watts. The spacing of units is proportional to the width ; that is, with a width of 16 feet, correct spacing is 8 feet between centres and 4 feet between units and the walls. With a spacing of 10 feet down the shop, the average foot-candles are as shown in the table.

Fig. 87.—Design 5.



Mounting Height of Enclosing Units—Not less than 9 ft. above floor.
Suspension Distance to Top of Bowl Units—1½ to 2½ ft.

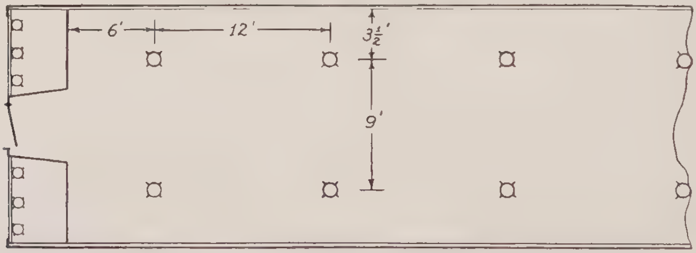
Approximate Average Foot-Candles Using 150-watt Gasfilled Lamps

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	6½	5½	5	4
Enclosing—Light Directing, or Semi-Enclosing	7½	6½	6	5
Semi-Indirect or Totally Indirect	6	5	4	—

Design 6.

In this design the width of the shop is the same—16 feet—but the height is 14 feet; this enables us to alter our spacing ratio in both directions, and, with higher-wattage lamps, so considerably increase

Fig. 88.—Design 6.



Mounting Height of Enclosing Units—Not less than 10 ft. above floor
Suspension Distance to Top of Bowl Units—2 to 3 ft.

Approximate Average Foot-Candles Using 200-watt Gasfilled Lamps

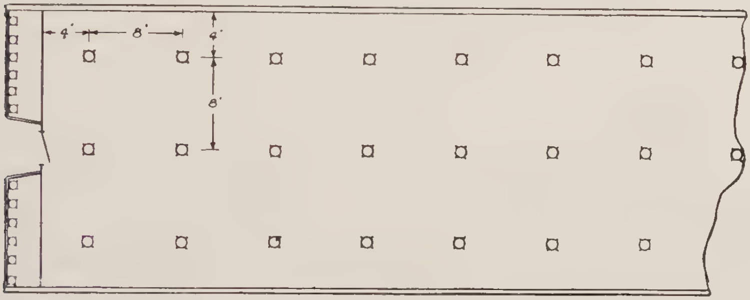
Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	8	6½	6	5
Enclosing—Light Directing, or Semi-Enclosing	9	8	7½	6½
Semi-Indirect or Totally Indirect	7	6	5	—

the average intensity. Across the width the spacing is 9 feet between centres and 3½ feet between units and the walls. Down the shop the spacing is increased to 12 feet. As will be seen from the table, the approximate increase is almost in proportion to the increased watts expended in lamps, but the latter is over a greater area, and therefore the design is more economical than the previous one.

Design 7.

With an increase in the number of light sources the distribution of light will be better. In this design the width of the interior is 24 feet and the spacing ratio is the same in both directions; that is, the distance between units is 8 feet, and between units and walls 4 feet; the height of the ceiling is 12 feet. 100-watt lamps are used, so that the wattage per square foot is ·64 watt. The average foot-candles is shown in the table.

Fig. 89.—Design 7.



Mounting Height of Enclosing Units—Not less than 8 ft. above floor
Suspension Distance to Top of Bowl Units—1½ to 2 ft.

Approximate Average Foot-Candles Using 100-watt Gasfilled Lamps

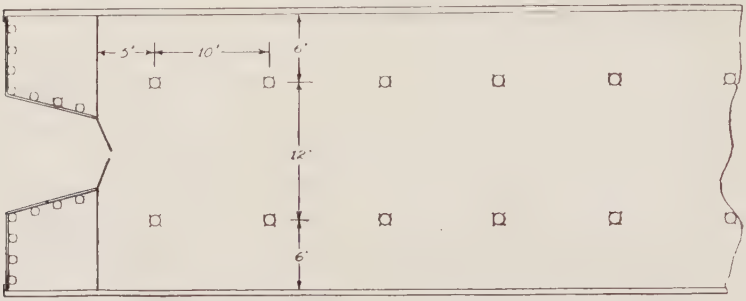
Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	6½	6	5	4
Enclosing—Light Directing, or Semi-Enclosing	7	6½	6	5
Semi-Indirect or Totally Indirect	6	5½	4	—

Design 8.

This design should be considered in conjunction with the previous design. The spacing of the interior is the same, but the height is 14 feet. A correct spacing ratio is adopted for width, but down the shop the spacing between centres is 10 feet. It will be seen that 200-watt lamps are used. The expenditure in watts per square foot is ·6 watt.

The table showing the average foot-candles in this design should be compared with the foot-candles in design 7. It will then be seen that this design is more economical in every way, despite the mounting height being 2 feet higher. It should be repeated, however, that in design 7 the distribution of light is better.

Fig. 90.—Design 8.



Mounting Height of Enclosing Units—Not less than 10 ft. above floor.
Suspension Distance to Top of Bowl Units—1½ to 2½ ft.

Approximate Average Foot-Candles Using 200-watt Gasfilled Lamps

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	7½	6½	5½	4½
Enclosing—Light Directing, or Semi-Enclosing	8½	7½	7	6
Semi-Indirect or Totally Indirect	6½	5½	4½	—

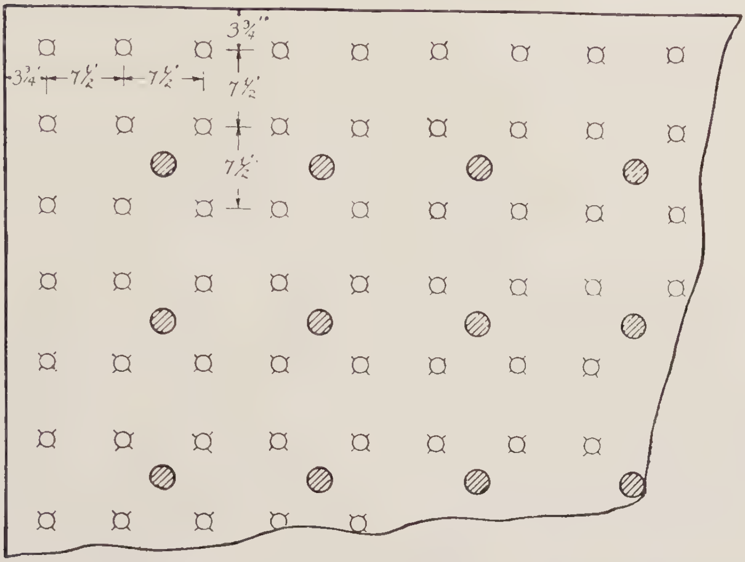
Design 9.

When the width of an interior exceeds 24 feet it is usually divided into bays; such an interior is illustrated in Fig. 91. Up to the moment the usual practice has been to instal one unit in the centre of each bay. This is good practice, provided height and spacings can be adapted to a suitable light source. Even then the total width of the interior must be taken into consideration, because, with the same spacing, the intensities vary with the width. This is shown in this design, which is for an interior in which the bays are approximately 15 feet by 15 feet, with a ceiling height of 11 feet. The units are equipped with 100-watt gas-filled lamps, and the spacing is symmetrical, that is, 7½ feet between centres and 3¾ feet between units and walls. The average foot-candles for widths of 30 feet and 60 feet respectively are given in the tables; it will be seen that for the wider interior the intensities are higher.

Design 10.

In this design the width of the bay is the same as in the previous one. The spacing, however, is doubled, since there is now only one

Fig. 91.—Design 9.



Mounting Height of Enclosing Units—Not less than 8 ft. above floor.

Suspension Distance to Top of Bowl Units—1¼ to 2 ft.

FOOT-CANDLES OF ILLUMINATION

Small Interiors—30 ft. wide

Approximate Average Foot-Candles Using 100-watt Gasfilled Lamps

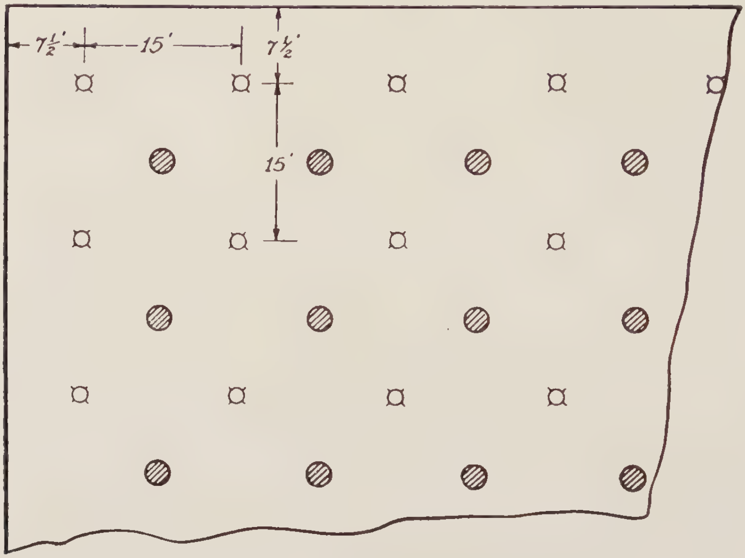
Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	7	6	5½	4
Enclosing—Light Directing, or Semi-Enclosing	7½	7	6½	5½
Semi-Indirect or Totally Indirect	6	5½	4½	—

Large Interiors—60 ft. wide or wider

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	8½	7½	6½	5½
Enclosing—Light Directing, or Semi-Enclosing	9	8½	7½	7
Semi-Indirect or Totally Indirect	7½	7	5½	—

unit per bay ; a 300-watt lamp is used in each unit. The foot-candle intensities are given in the tables for two widths as before. This design should be considered in conjunction with the previous one. The minimum ceiling height is 12 feet.

Fig. 92.—Design 10.



Mounting Height of Enclosing Units—Not less than 11 ft. above floor.

Suspension Distance to Top of Bowl Units—2½ to 3½ ft

FOOT-CANDLES OF ILLUMINATION

Small Interiors—30 ft. wide

Approximate Average Foot-Candles Using 300-watt Gasfilled Lamps.

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	5½	4½	4	3
Enclosing—Light Directing, or Semi-Enclosing	6	5½	5	4
Semi-Indirect or Totally Indirect	5	4	3½	-

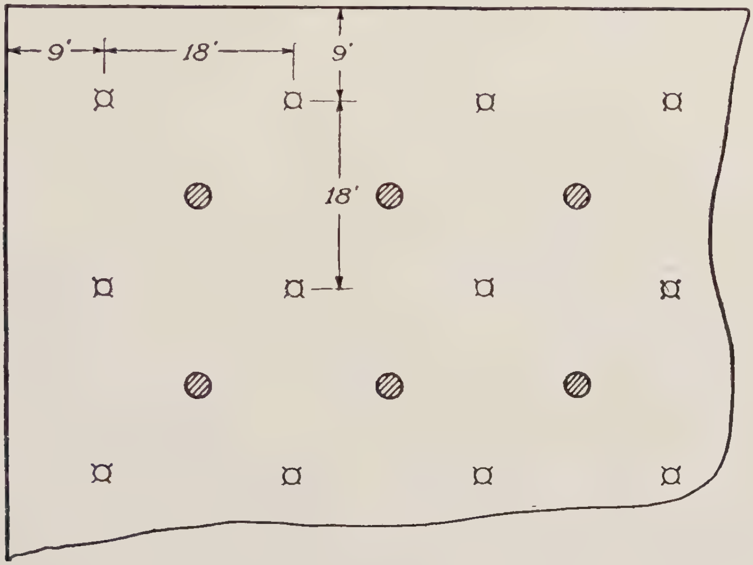
Large Interiors—60 ft. wide or wider

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	7	6	5½	4½
Enclosing—Light Directing, or Semi-Enclosing	8	7	6½	6
Semi-Indirect or Totally Indirect	6½	5½	4½	-

Design 11.

This design is similar to the last, with the exception that the bays are 18 feet by 18 feet, the lamps used are 500-watt, and the minimum ceiling height is 14 feet. The ratio between width of bays and width of interiors should be noted and the foot-candle intensities considered.

Fig. 93.—Design 11.



Mounting Height of Enclosing Units—Not less than 13 ft above floor.

Suspension Distance to Top of Bowl Units—3 to 4½ ft.

FOOT-CANDLES OF ILLUMINATION

Small Interiors—36 ft. wide

Approximate Average Foot-Candles Using 500-watt Gasfilled Lamps

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	6½	5½	5	4
Enclosing—Light Directing, or Semi-Enclosing	8	7	6	5½
Semi-Indirect or Totally Indirect	6	5½	4	–

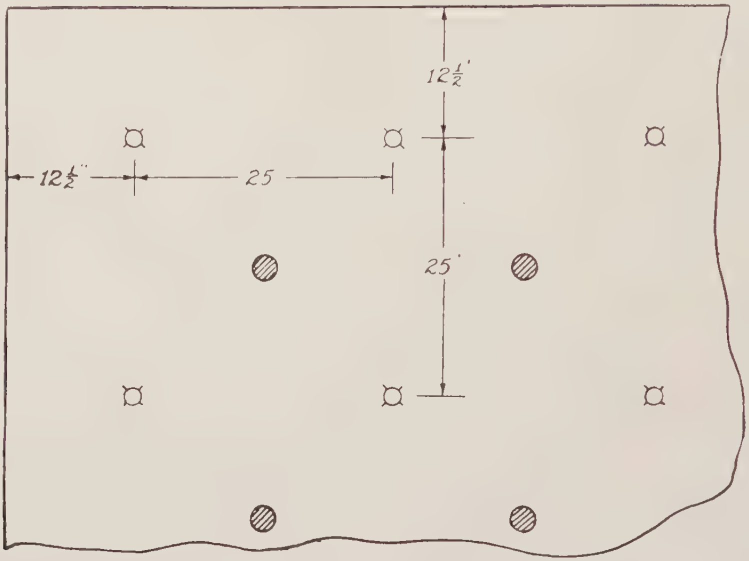
Large Interiors—72 ft. wide or wider

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	8½	7½	6½	5
Enclosing—Light Directing, or Semi-Enclosing	9½	8½	8	7
Semi-Indirect or Totally Indirect	7½	6½	5½	–

Design 12.

In this design the bays are very large, 25 feet by 25 feet ; the lamps are of 1000 watts, and the spacing between units is 25 feet. A correct

FIG. 94.—DESIGN 12.



Mounting Height of Enclosing Units—Not less than 16 ft. above floor.

Suspension Distance to Top of Bowl Units—4 to 6 ft.

FOOT-CANDLES OF ILLUMINATION

Small Interiors—50 ft. wide

Approximate Average Foot-Candles Using 1000-watt Gasfilled Lamps

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	7½	6½	5½	4½
Enclosing—Light Directing, or Semi-Enclosing	9	8	7	6
Semi-Indirect or Totally Indirect	7	6	4½	—

Large Interiors—75 ft. wide or wider

Type of Fitting	Light Ceiling		Medium Ceiling	Dark Ceiling
	Light Walls	Medium Walls	Medium Walls	Dark Walls
Enclosing—Light Diffusing ...	11½	10	8½	7½
Enclosing—Light Directing, or Semi-Enclosing	12½	11½	10	9
Semi-Indirect or Totally Indirect	10	9	7½	—

spacing ratio has been adopted, and in the larger interiors it will be seen that such a high intensity as $12\frac{1}{2}$ foot-candles has been obtained.

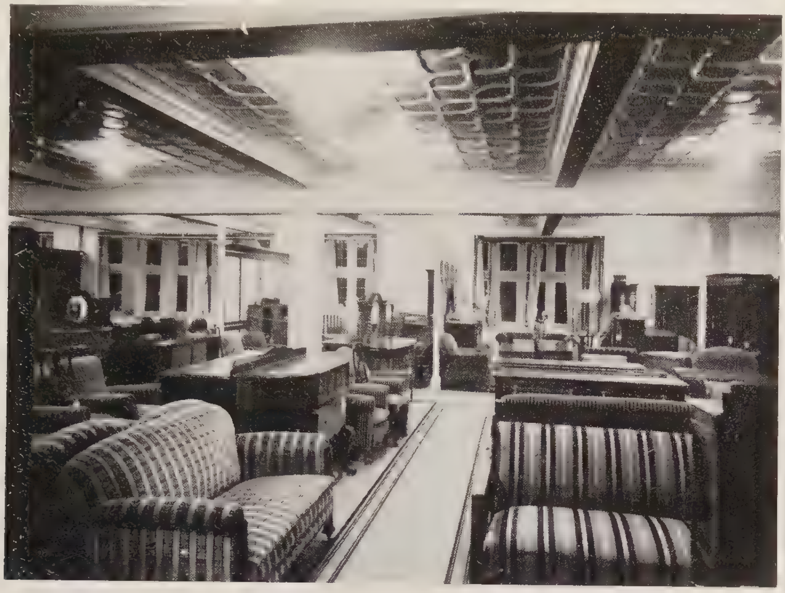


FIG. 95.—GLARE HERE IS UNAVOIDABLE. IT IS CAUSED THROUGH A VARNISHED CEILING.

Show-case Lighting.—An essential feature of our large shops and stores is the show-case, which in reality is a miniature shop window. Its illumination calls for the same care as an interior, from the fact that clear vision is desirable; shadows should be eliminated, and the light sources should be out of the line of vision.

One of the best methods of show-case lighting is by means of tubular lamps fitted in the top of the case and shielded to prevent glare. It is not necessary, in this type of lighting, to use lamps of a wattage higher than 20 watts; if sufficient of them are used, show-cases will be brightly illuminated and will at once attract attention.

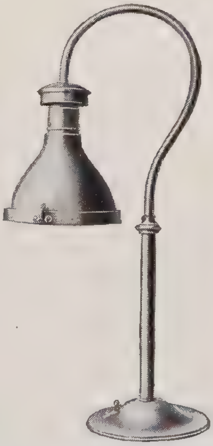


FIG. 96.—COLOUR-MATCHING UNIT.

Daylight Units.—For ordinary purposes, artificial illumination will be found to be satisfactory from a colour point of view. It is usual, however, when a customer desires to match colours, to examine various coloured materials under artificial light which, from a colour quality point of view, approximates to daylight. Colour-matching is carried out by means of a special lighting unit which is equipped with filters, so that the undesirable rays are eliminated. Such a unit is illustrated in Fig. 96.

TABLE IX

COLOUR OF LIGHT FALLING UPON FABRICS

Original Colour of Fabric	Red	Orange	Yellow	Green	Blue	Violet
Black	Purplish black	Deep maroon	Yellow-olive	Greenish brown	Blue-black	Faint violet-black
White	Red	Orange	Light yellow	Green	Blue	Violet
Red	Intense red	Scarlet	Orange	Brown	Violet	Red violet-purple
Orange	Orange-red	Intense orange	Yellow-orange	Faint yellow, slightly greenish	Brown, slightly violet	Light red
Yellow	Orange	Yellow-orange	Orange-yellow	Yellowish green	Green	Brown tinged with faint red
Light green	Reddish grey	Yellow-green	Greenish yellow	Intenser green	Blue-green	Light purple
Deep green	Reddish black	Rusty green	Yellowish green	Intenser green	Greenish blue	
Light blue	Violet	Orange-grey	Yellowish green	Green-blue	Vivid blue	
Deep blue		Grey slightly on orange	Green-slate	Blue-green	Intenser blue	Bright blue-violet
Indigo-blue		Orange-maroon	Orange-yellow (very dull)	Dull green	Dark blue-indigo	Deep blue-violet
Violet	Purple	Red-maroon	Yellow-maroon	Bluish green-brown	Deep bluish violet	Deep violet

TABLE X

PRESENT STANDARDS OF FOOT-CANDLE ILLUMINATION FOR SHOPS

	Foot-Candles	
	Recommended	Under some conditions
Show windows—		
Large cities—		
Brightly lighted district	**75**	50–150
Secondary business locations	**50**	25–75
Suburban shops	**25**	10–50
Medium cities—		
Brightly lighted district	**50**	25–75
Suburban shops	**25**	10–50
Small towns	**25**	10–50
Large shops—		
Main floors	**10**	6–12
Basement floor	**10**	6–12
Other floors	**8**	5–10
Shops of medium size—		
Clothing, furniture, etc.	**8**	5–10
Small specialized shops—		
Light goods	**8**	5–10
Dark goods	**12**	8–16
Small shops—		
Types of—		
Art	**8**	5–10
Bakers	**6**	4–8
Book	**6**	4–8
Boots	**8**	5–10
Butchers	**8**	4–8
Chemist	**8**	5–10
China	**6**	4–8
Cigar	**8**	5–10
Clothing	**8**	5–10
Confectionery	**8**	5–10
Dairy products	**6**	4–8
Decorator	**8**	5–10
Electrical supplies	**8**	5–10
Florist	**6**	4–8
Furrier	**8**	5–10
Grocery	**6**	4–8
Haberdashery	**8**	5–10
Hairdresser	**8**	5–10
Hardware	**6**	4–8
Hatters	**8**	5–10
Jewellery	**8**	5–10
Leather, handbags, and trunks	**6**	4–8

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles Recommended	Foot-Candles Under some conditions
Small shops (*continued*)—		
Milliners	8	5–10
Motor accessories	6	4–8
Music	6	4–8
Opticians	8	5–10
Sports ware	6	4–8
Tailor	8	5–10
Tobacconist	8	5–10
Toys	6	4–8

PRESENT STANDARDS OF FOOT-CANDLE ILLUMINATION FOR INTERIORS OF COMMERCIAL AND PUBLIC BUILDINGS

	Foot-Candles Recommended	Foot-Candles Under some conditions
Automobile showroom	8	5–10
Bank—		
Lobby	6	4–8
Offices	8	6–12
Carriages (public transport)—		
Luggage van	6	5–10
Ordinary carriages, dining and Pullman car	8	6–12
Mail-van sorting-racks	10	8–16
Corridors	3	2–4
Bus and tramcars	8	6–12
Churches—		
Church	3	2–4
Lecture-room	5	3–6
Cinema—		
During interval	3	2–4
During pictures	0·1	0·1–0·2
Clubrooms	4	3–6
Dance-halls	4	3–6
Dentist—		
Waiting-room	4	3–6
Surgery	15	10–20
Drawing-office	15	10–20
Garage	2	1–2
Garage repair department	8	5–10
Gymnasiums—		
Fencing, boxing, wrestling	8	5–10
Swimming-bath	4	3–6
Shower-bath	4	3–6
Dressing-rooms	4	3–6

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles	
	Recommended	Under some conditions
Hospitals—		
Waiting- and receiving-room	**4**	3–6
Corridors	**3**	2–4
Wards and private rooms with local illumination	**3**	2–4
Wards and private rooms ,, night illumination	**0·1**	0·1–0·2
Operating-table	**75**	50–100
Operating-room	**10**	6–12
Laboratories	**10**	6–12
Hotels—		
Lounge	**4**	3–6
Dining-room	**5**	4–8
Writing-room	**8**	5–10
Kitchen	**6**	4–8
Bedrooms	**6**	4–8
Corridors	**2**	2–4
Indoor recreations—		
Bowling (on alley, runway, and seats)	**5**	3–6
(on pins)	**15**	10–20
Billiards (general)	**2**	1–3
(on table)	**15**	10–20
Racquet, badminton, squash, and indoor tennis	**15**	10–20
Skating-rinks	**5**	4–8
Library—		
Reading-rooms	**8**	5–10
Book-room	**4**	3–6
Lifts (passenger and goods)	**4**	3–6
Lunch-room	**5**	4–8
Market	**8**	5–10
Museum (general)	**5**	4–8
(on walls)	**8**	5–10
Office buildings—		
General office	**8**	6–12
Private offices	**8**	6–12
Typing and book-keeping rooms	**8**	6–12
Filing-room	**4**	3–6
Vault	**4**	3–6
Public halls	**5**	3–6
Restaurants	**5**	4–8
Schools—		
Blackboards	**6**	4–8
Classrooms, library, and office	**8**	5–10
Corridors and stairways	**3**	2–4
Drawing	**15**	10–20
Laboratories	**10**	6–12

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles	
	Recommended	Under some conditions
Schools (*continued*)—		
Lecture-theatre	**5**	4–8
Manual training	**10**	6–12
Sewing-rooms	**15**	10–20
Studios—		
Art and photographic	**10**	6–12
Moving picture—general	**5**	3–6
Portraiture (photographic daylight)	..	500–2000
Telephone exchanges	**5**	3–6
Theatres—		
Auditorium	**4**	3–6
Foyer	**5**	3–6
Lobby	**8**	5–10
Toilet- and wash-rooms	**4**	3–6
Waiting-room	**4**	3–6
Works interiors—		
Offices—		
Private, general	**10**	6–12
Drawing-office	**15**	10–20
Dressing-rooms	**4**	2–4
Aisles, stairways, passage-ways, and corridors	**3**	2–4
Assembling shops—		
Rough work	**5**	3–6
Medium ,,	**5**	3–6
Fine ,,	**10**	8–16
Extra fine work	**10–50**	....
Store- and stock-rooms—		
Rough	**3**	2–4
Medium	**6**	4–8
Toilet- and wash-rooms	**4**	3–6

PRESENT STANDARDS OF FOOT-CANDLE ILLUMINATION FOR INDUSTRIAL INTERIORS

	Foot-Candles	
Types of Works :—	Recommended	Under some conditions
Bakeries	**8**	5–10
Bookbinding—		
Folding, assembling, pasting, etc.	**5**	3–6
Cutting, punching, and stitching	**8**	5–10
Embossing	**10**	8–12

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles	
	Recommended	Under some conditions
Chemical works—		
Hand furnaces, boiling-tanks, stationary driers, stationary or gravity crystallizing	**3**	2–4
Mechanical furnaces, generators and stalls, mechanical driers, evaporators, filtration, mechanical crystallizing, bleaching	**4**	3–6
Tanks for cooking, extractors, percolators, nitrators, electrolytic cells	**6**	4–8
Clay products and cements—		
Grinding, filter pressing, kiln-rooms	**3**	2–4
Moulding, pressing, cleaning, and trimming	**5**	3–6
Enamelling	**6**	4–8
Colouring and glazing	**10**	6–12
Cloth products—		
Light goods	**10**	6–12
Dark goods	**20**	10–50
Coal breaking and washing, screening	**3**	2–4
Construction—indoor general	**3**	2–4
Cutting, inspecting, sewing, pressing, cloth treating (oilcloth, etc.)—		
Light goods	**8**	5–10
Dark goods	**12**	8–16
Dairy products	**6**	5–10
Electric manufacturing—		
Storage battery, moulding of grids, charging-room	**6**	4–8
Coil- and armature-winding, mica-working, insulating processes	**10**	8–16
Engraving	**20**	10–50
Foundries [1]—		
Charging-floor, tumbling, cleaning, pouring and shaking-out	**5**	3–6
Rough moulding and core-making	**6**	4–8
Fine moulding and core-making	**10**	6–12
Flour-milling—		
Cleaning, grinding, or rolling	**5**	3–6
Baking or roasting	**8**	5–10
Flour-grading	**16**	10–20

[1] Since pouring and shaking-out are carried on in the same location as either rough or fine moulding, different illumination levels may be secured for these operations by cutting out some of the lighting circuits when space is used for the former.

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles	
	Recommended	Under some conditions
Glass works—		
Mix- and furnace-rooms, pressing, glass-blowing machines	**6**	4–8
Grinding, cutting glass to size, silvering	**8**	5–10
Fine grinding, polishing, bevelling, inspection, etching, and decorating	**10**	6–12
Glass-cutting (cut glass), inspecting fine	**10–50**	....
Glove manufacturing—		
Light goods—		
Cutting, pressing, knitting	**8**	5–10
Sorting, stitching, trimming, and inspecting	**10**	8–16
Dark goods—		
Cutting, pressing, knitting	**10**	6–12
Sorting, stitching, trimming, and inspecting	**20**	10–50
Hat manufacturing—		
Dyeing, stiffening, braiding, cleaning, and refining—		
Light	**6**	4–8
Dark	**10**	6–12
Forming, sizing, pouncing, flanging, finishing, ironing—		
Light	**8**	5–10
Dark	**10**	6–12
Sewing—		
Light	**10**	8–16
Dark	**10–50**	....
Ice-making engine and compressor room	**6**	4–8
Inspecting—		
Rough	**6**	4–8
Medium	**10**	6–12
Fine	**15**	10–20
Extra fine	**10–50**	....
Jewellery and watch manufacturing	**10–50**	....
Laundries and dry-cleaning	**8**	5–10
Leather manufacturing—		
Vats	**3**	2–4
Cleaning, tanning, and stretching	**4**	3–6
Cutting, fleshing, and stuffing	**6**	4–8
Finishing and scarfing	**10**	6–12
Leather working—		
Pressing and winding—		
Light	**8**	5–10
Dark	**10**	6–12

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles	
	Recommended	Under some conditions
Leather working (*continued*)—		
Grading, matching, cutting, scarfing, sewing—		
Light	**10**	8–16
Dark	**10–50**	....
Machine shops—		
Rough bench and machine work	**6**	4–8
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing, and polishing	**10**	6–12
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing, and polishing	**12**	8–16
Extra fine bench and machine work, grinding (fine work)	**10–50**	....
Meat factory—		
Slaughtering	**5**	3–6
Cleaning, cutting, cooking, grinding, canning, packing	**8**	5–10
Packing—		
Crating	**4**	3–6
Boxing	**6**	4–8
Paint manufacturing	**6**	4–8
Paint-shops—		
Dipping, spraying, firing	**5**	3–6
Rubbing, ordinary hand painting and finishing	**8**	5–10
Fine hand painting and finishing	**10**	8–16
Extra fine hand painting and finishing (automobile bodies, piano cases, etc.)	**15**	10–50
Paper box manufacturing—		
Light	**6**	4–8
Dark	**8**	5–10
Storage of stock	**3**	2–4
Paper manufacturing—		
Beaters, grinding	**4**	3–6
Calendering	**6**	4–8
Finishing, cutting, and trimming	**8**	6–12
Plating	**5**	3–6
Polishing and burnishing	**8**	5–10
Power houses—		
Boilers, coal and ash handling, storage battery rooms	**3**	2–4
Auxiliary equipment, oil switches, and transformers	**5**	3–6

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles	
	Recommended	Under some conditions
Power-houses (*continued*)—		
Switch-boards, engines, generators, blowers, compressors	**6**	4–8
Printing industries—		
Matrixing and casting, miscellaneous machines, presses	**8**	5–10
Proof-reading, lithographing, electrotyping	**10**	6–12
Linotype, monotype, typesetting, imposing, stone engraving	**12–50**	....
Sorting and packing	**5**	3–6
Rubber manufacturing and products—		
Calenders, compounding mills, fabric preparation, stock cutting, tubing machines, solid-tyre operations, mechanical goods building, vulcanizing	**8**	5–10
Bead building, pneumatic-tyre building and finishing, inner tube operation, mechanical goods trimming, treading	**10**	8–16
Sheet-metal works—		
Miscellaneous machines, ordinary bench work	**8**	5–10
Punches, presses, shears, stamps, welders, spinning, fine bench work	**10**	8–16
Tinplate inspection	**15**	10–20
Shoe manufacturing—		
Hand turning, miscellaneous bench and machine work	**8**	5–10
Cutting, lasting, and welting (light)	**10**	6–12
Stitching (local lights)	**20–50**	....
Inspecting and sorting raw material, cutting: light	**10**	....
Inspecting and sorting raw material, cutting: dark	**10–50**	....
Smith shops and welding—		
Rough forging	**6**	4–8
Fine forging and welding	**10**	6–12
Soap manufacturing—		
Kettle houses, cutting, soap chip and powder	**5**	3–6
Stamping, wrapping, and packing, filling and packing soap powder	**6**	4–8
Steel and iron mills, bar, sheet, and wire products—		
Soaking pits and reheating furnaces	**2**	1–3
Charging and casting floors	**4**	3–6
Muck and heavy rolling, shearing rough by gauge, pickling and cleaning	**5**	3–6
Plate inspection	**15**	10–20
Automatic machines, rod, light, and cold rolling, wire drawing, shearing fine by line	**8**	5–10

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles	
	Recommended	Under some conditions
Stone crushing and screening—		
Belt conveyor tubes, main-line shafting spaces, chute-rooms, inside of bins	2	1–2
Primary breaker room, auxiliary breakers under bins	3	2–4
Screen-rooms	5	3–6
Structural steel works	6	4–8
Sugar-grading	15	10–20
Sweet-making	8	5–10
Testing—		
Rough	5	3–6
Fine	10	6–12
Extra fine instruments, scales, etc.	20	10–50
Textile mills—		
Cotton—		
Opening and lapping, carding, drawing frame, roving, dyeing	5	3–6
Spooling, spinning, drawing in, warping, weaving, quilling, inspecting, knitting, slashing (over beam end)	8	5–10
Silk—		
Winding, throwing, dyeing	12	8–16
Quilling, warping, weaving, and finishing—		
Light goods	8	5–10
Dark goods	10	8–16
Woollen—		
Carding, picking, washing, and combing	4	3–6
Twisting and dyeing	6	4–8
Drawing in, warping—		
Light goods	6	4–8
Dark goods	10	8–16
Weaving—		
Light goods	8	5–10
Dark goods	12	10–20
Knitting machines	10	6–12
Tobacco products—		
Drying, stripping, general	2	1–3
Grading and sorting	15	10–20
Upholstering—		
Automobile, coach, and furniture	8	6–12
Warehouse	2	1–2
Wood working—		
Rough sawing and bench work	5	3–6

Note that glare must be avoided.

TABLE X—*continued.*

	Foot-Candles Recommended	Foot-Candles Under some conditions
Wood-working—*continued*—		
Sizing, planing, rough sanding, medium machine and bench work, glueing, veneering, cooperage	8	5–10
Fine and bench and machine working, fine sanding and finishing	8	6–12

Note that glare must be avoided.

Choice of Reflecting Equipment

Various lighting units are judged in accordance with the following six fundamentals:—(1) Direct glare; (2) reflected glare; (3) shadows; (4) efficiency based upon horizontal illumination; (5) maintenance; (6) vertical illumination. On the other hand, where lamps are to be hung above a crane in a foundry, the order of importance would be:—(1) Efficiency based upon horizontal illumination; (2) vertical illumination; (3) maintenance; (4) shadows; (5) direct glare; (6) reflected glare.

In the following chart the best rating given is A+, which denotes the highest degree of excellence, while D, the lowest, indicates that an installation of units, so rated in any particular, will very likely prove unsatisfactory in an installation where this factor is important. The ratings B and C, while indicating a result not equal to A, are decidedly superior to rating D. In other words, a rating B, C+, or C in certain respects does not disqualify a unit, provided that in the essential requirements of a given location the unit is rated A or B+.

$$\left.\begin{matrix}A+\\A\\A-\end{matrix}\right\}\text{Excellent}\qquad\left.\begin{matrix}B+\\B\\B-\end{matrix}\right\}\text{Good}\qquad\left.\begin{matrix}C+\\C\\C-\end{matrix}\right\}\text{Fair}\qquad\text{D, Very bad}$$

Note.—Table XI is intended to show representative equipment of different constructions. Hence some which have a very limited application, such as No. 7, conical reflector with clear lamps, are included merely for purposes of comparison, while at the same time many equipments of wide application, but generally similar in performance to these listed, have been omitted on account of space limitations.

It is important that good reflecting equipment be installed. The fittings shown in these charts illustrate certain types. For example, No. 15 and No. 16 show units of a general type of which there are a great variety made by various manufacturers. Of two or more units of the same type the choice should be governed by considerations of brightness, diffusion, absorption, appearance, and cost, and not by cost alone. Of two samples of glass enclosing globes, outwardly identical, one may absorb 30% of the light and the other only 15% for the same degree of diffusion. Products of reliable manufacture should be used in order to ensure results being in accordance with the figures given in this book.

TABLE XI

A GUIDE TO THE SELECTION OF REFLECTING EQUIPMENT

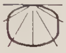
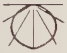
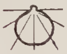
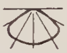
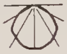
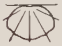
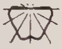
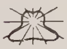
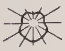
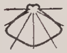
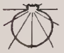
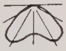
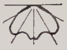
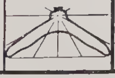
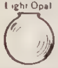
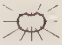
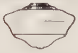
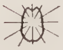
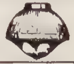
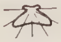
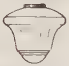
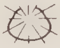
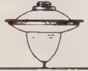
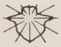
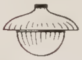
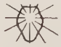
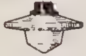
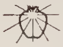
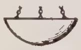
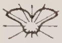
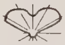
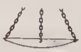
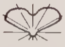
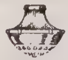
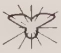
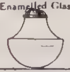
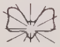
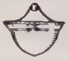
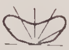
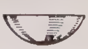
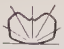
LIGHTING UNIT			EFFICIENCY BASED UPON		FAVOURABLE APPEARANCE OF LIGHTED ROOM	DIRECT GLARE	REFLECTED GLARE	SHADOWS	MAINTENANCE
			ILLUMINATION ON HORIZONTAL	ILLUMINATION ON VERTICAL					
DIRECT LIGHTING PORCELAIN ENAMEL REFLECTORS									
1	DISPERSIVE Clear Lamp		A+	B+	C+	C	D	C+	A+
2	DISPERSIVE Bowl-Sprayed Lamp		A−	B	B	B+	B	B+	A−
3	REFLECTOR DIFFUSER		B+	B	A−	A−	B+	A−	B+
4	DEEP BOWL Clear Lamp		B+	B−	C	C+	D	C	A
5	DEEP BOWL Bowl-Sprayed Lamp		B	C+	C	B	C+	C+	B+
6	DISTRIBUTING REFLECTOR		B	B	C−	C−	D	C−	B+
7	ENAMELLED IRON SHADE Clear Lamp		B−	C	C	D	D	C−	B
DIRECT LIGHTING OPEN GLASS REFLECTORS									
8	LIGHT DENSITY OPAL Clear Lamp		B+	B	B+	C+	D	B−	B
9	LIGHT DENSITY OPAL Bowl-Sprayed Lamp		B	B−	A−	B−	B−	B+	B−
10	DENSE OPAL Clear Lamp		A+	B+	B+	B	D	C+	A−
11	DENSE OPAL Bowl-Sprayed Lamp		B+	B−	A−	B+	B−	B	B
12	MIRRORED GLASS Clear Lamp		A	B	C	C+	D	C	A−
13	MIRRORED GLASS Bowl-Sprayed Lamp		B	C+	C	B−	C	C+	B−
14	PRISMATIC INDUSTRIAL Clear Lamp		A+	A−	B+	C+	D	C+	B−

TABLE XI

A GUIDE TO THE SELECTION OF REFLECTING EQUIPMENT

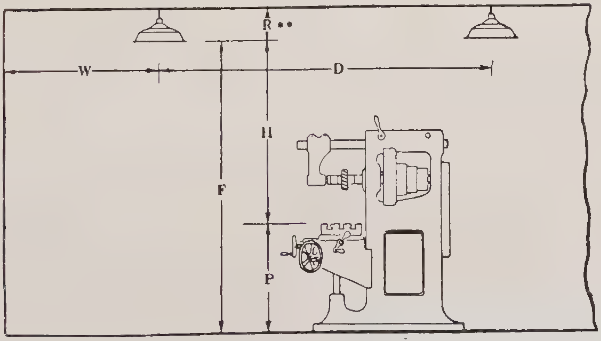
LIGHTING UNIT			EFFICIENCY BASED UPON		FAVOURABLE APPEARANCE OF LIGHTED ROOM	DIRECT GLARE	REFLECTED GLARE	SHADOWS	MAINTENANCE
			ILLUMINATION ON HORIZONTAL	ILLUMINATION ON VERTICAL					
DIRECT LIGHTING ENCLOSING AND SEMI ENCLOSING UNITS									
15	DIFFUSING GLOBE Light Opal 		B–	B–	A	B–	B	B+	B+
16	ONE-PIECE OPAL Flattened Reflecting Top 		B	B	A	B	B+	A–	A–
17	PRISMATIC ENCLOSING 		B+	B	A	B	B–	B+	B+
18	DEEP DIFFUSING 		B–	A	A	A	B+	A–	A–
19	ONE PIECE GLASS 		B	A	A	B+	B+	A–	A–
20	TWO-PIECE GLASS 		C+	B–	A	B+	B+	A–	B–
21	ONE-PIECE GLASS Enamelled Refl. and Bowl 		B	B	A	B+	B+	A–	A–
SEMI INDIRECT AND INDIRECT LIGHTING UNITS									
22	LIGHT OPAL 		B–	C+	A	B+	B+	A–	C
23	DENSE OPAL for Light Opal and Bowl-Sprayed Lamp		C+	C	A	A+	A–	A+	C
24	ALABASTER BOWL 		C+	C	A	A+	A–	A+	C
25	PRISMATIC ENCLOSED 		B+	C+	A	A–	A–	A–	B
26	CLEAR TOP ENCLOSED Enamelled Glass 		B–	C+	A	B+	B+	A	B
27	MIRRORED INDIRECT 		C+	C	B+*	A+	A	A+	C
28	ENAMELLED METAL INDIRECT 		C	C	B+	A+	A	A+	C

*For Luminous Bowl Type Rate A.

TABLE XII—SPACING: MOUNTING-HEIGHT

DIRECT LIGHTING UNITS, INCLUDING SEMI-ENCLOSING AND TOTALLY-ENCLOSING UNITS, No. 1 to No. 21

Mounting Height of Unit		Distance between Points	Distance between Points and Side Walls	
Above Plane of Work (H)	Above Floor * (F)	(D)	In Usual Locations where Aisles and Storage are next to Wall (W)	In Offices or where Work Benches are next to Wall (W)
4	6½	6	3	2
5	7½	7½	3½	2½
6	8½	9	4½	3
7	9½	10½	5	3½
8	10½	12	6	4
9	11½	13½	6½	4½
10	12½	15	7½	5
11	13½	16½	8	5½
12	14½	18	9	6
13	15½	19½	9½	6½
14	16½	21	10½	7
15	17½	22½	11	7½
16	18½	24	12	8
18	20½	27	13½	9
20	22½	30	15	10
22	24½	33	16½	11
24	26½	36	18	12
27	29½	40½	20	13½
30	32½	45	22½	15
35	37½	52½	26	17½
40	42½	60	30	20



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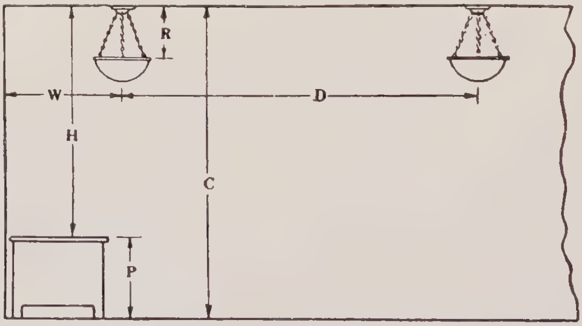
* Plane of work (P) assumed to be 2½ feet above floor. When the plane of work is higher or lower than 2½ feet above floor, neglect column (F) and work from column (H).

** Minimum allowance for (R) usually 1 foot.

TABLE XIII—SPACING : MOUNTING-HEIGHT

SEMI- AND TOTALLY-INDIRECT LIGHTING UNITS, No. 22 to No. 28

Ceiling Height		Spacing Distance between Points	Distance between Points and Side Walls		Suspension Distance Ceiling to Top of Reflector **
Above Plane of Work (H)	Above Floor * (C)	(D)	In Usual Locations where Aisles and Storage are next to Wall (W)	In Offices or where Work Benches are next to Wall (W)	(R)
5	7½	7½	3½	2½	1¼
6	8½	9	4½	3	1½
7	9½	10½	5	3½	1¾
8	10½	12	6	4	2
9	11½	13½	6½	4½	2¼
10	12½	15	7½	5	2½
11	13½	16½	8	5½	2¾
12	14½	18	9	6	3
13	15½	19½	9½	6½	3¼
14	16½	21	10½	7	3½
15	17½	22½	11	7½	3¾
16	18½	24	12	8	4
18	20½	27	13½	9	4½
21	23½	31½	15½	10½	5¼
24	26½	36	18	12	6
27	29½	40½	20	13½	6¾
30	32½	45	22½	15	7½
35	37½	52½	26	17½	8¾
40	42½	60	30	20	10



* Plane of work (P) assumed to be 2½ feet above floor. When the plane of work is higher or lower than 2½ feet above floor, neglect column (C) and work from column (H).

** Suspension distances (R) in Table are based on best distribution of light and efficiency of utilization for standard units. In some installations other considerations may require a different suspension distance.

TABLE XIV—ROOM INDEX

Classify the room according to the proportions and the mounting height above the plane of work. Use upper column headings for direct-lighting units; for semi-indirect and totally indirect units choose column at bottom of page. Wherever the circumstances are such that the room index falls between two given figures, interpolate or use the smaller number.

Room Width	Room Length	DIRECT LIGHTING UNITS—Height Above Plane of Work FEET													
FEET	FEET	4	5	6	7	8	9	10	12	14	16	20	24	30	40
8	10	1.0	0.8	0.8	0.6	0.6	0.6	0.6	...	...	...	...	...	...	...
	12	1.25	0.8	0.8	0.6	0.6	0.6	0.6	...	...	...	...	...	...	...
	16	1.25	1.0	0.8	0.6	0.6	0.6	0.6	...	...	...	...	...	...	...
	24	1.5	1.25	1.0	0.8	0.6	0.6	0.6	0.6	0.6	...	...	...	...	...
	35	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0.6	0.6	0.6	...	...	...	...
	50	2.0	1.5	1.25	1.0	1.0	0.8	0.8	0.6	0.6	0.6	...	...	...	...
10	10	1.25	1.0	0.8	0.6	0.6	0.6	0.6	...	...	...	...	...	...	...
	14	1.5	1.0	1.0	0.8	0.6	0.6	0.6	0.6	...	...	...	...	...	...
	20	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	0.6	...	...	...	...	...
	30	2.0	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	0.6	...	...	...	...
	40	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	0.6	...	...	...
	70	2.0	1.5	1.5	1.25	1.25	1.0	1.0	0.8	0.8	0.6	0.6	...	...	...
12	12	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	...	...	...	...	...	...
	18	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0.6	0.6	...	...	...	...	...
	24	2.0	1.5	1.25	1.0	1.0	0.8	0.8	0.6	0.6	0.6	...	...	...	...
	35	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	0.6	...	...	...
	50	2.0	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	0.6	...	...
	90	2.0	2.0	1.5	1.5	1.25	1.25	1.25	1.0	0.8	0.8	0.6	0.6	...	...
14	14	1.5	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	...	...	...	...	...
	24	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	...	...	...	...
	40	2.5	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	0.6	...	...
	70	2.5	2.0	2.0	1.5	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0.6	...	...
	100	2.5	2.0	2.0	1.5	1.5	1.5	1.5	1.25	0.8	0.8	0.6	0.6	...	...
16	16	2.0	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0.6	0.6	...	...	...	...
	30	2.5	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	...	...	...
	50	2.5	2.0	2.0	1.5	1.5	1.25	1.25	1.0	0.8	0.6	0.6	0.6	0.6	...
	80	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	0.6	...
	120	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0	0.8	0.8	0.6	...
18	18	2.0	2.0	1.5	1.25	1.0	1.0	0.8	0.8	0.6	0.6	...	...	...	...
	35	3.0	2.5	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	...	...
	50	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.8	0.6	0.6	0.6	...
	80	3.0	2.5	2.0	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.8	0.6	0.6	...
	120	3.0	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.25	1.0	0.8	0.8	0.6	...
		6	7½	9	10½	12	13½	15	18	21	24	30	36	45	60
		FEET SEMI & INDIRECT LIGHTING UNITS—Ceiling Height Above Plane of Work													

TABLE XIV—ROOM INDEX

Room Width	Room Length	DIRECT LIGHTING UNITS—Height Above Plane of Work FEET													
FEET	FEET	4	5	6	7	8	9	10	12	14	16	20	24	30	40
20	20	2.5	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	0.6	...	...	...
	40	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.8	0.6	0.6	...	...
	60	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	0.6	0.6
	100	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	0.6
	140	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.25	1.25	1.0	0.8	0.6	0.6
24	24	3.0	2.5	2.0	1.5	1.5	1.25	1.25	1.0	0.8	0.8	0.6	0.6	...	...
	50	3.0	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	...
	70	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	0.6
	100	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6
	160	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.25	1.0	0.8	0.6
30	30	4.0	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	1.0	0.8	0.6	0.6	...
	60	4.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.25	1.25	1.0	0.8	0.6	0.6
	100	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0	0.8	0.6	0.6
	140	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.25	1.0	0.8	0.6
35	35	4.0	3.0	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6	...
	70	5.0	4.0	3.0	3.0	3.0	2.5	2.0	2.0	1.5	1.5	1.0	0.8	0.6	0.6
	100	5.0	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.25	1.0	0.8	0.6
	140	5.0	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.25	0.8	0.6
40	40	5.0	4.0	3.0	3.0	2.5	2.0	2.0	1.5	1.5	1.25	1.0	0.8	0.6	0.6
	80	5.0	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.25	1.0	0.8	0.6
	140	5.0	4.0	3.0	3.0	3.0	2.5	2.5	2.5	2.0	2.0	1.5	1.25	1.0	0.8
50	50	5.0	5.0	4.0	4.0	3.0	2.5	2.5	2.0	2.0	1.5	1.25	1.0	0.8	0.6
	100	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.5	2.0	1.5	1.25	1.0	0.8
	200	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.5	2.5	2.0	1.5	1.25	1.0
60	60	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	2.0	1.5	1.25	1.0	0.8
	100	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	1.5	1.5	1.25	1.0
	200	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.0	2.0	1.5	1.0
70	70	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	1.5	1.5	1.25	0.8
	140	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.0	2.0	1.5	1.0
	200	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.0	1.5	1.25
80	80	5.0	5.0	5.0	5.0	5.0	4.0	4.0	4.0	3.0	2.5	2.0	1.5	1.25	1.0
	140	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	3.0	2.5	2.0	1.25
100	100	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	2.5	2.0	1.5	1.25
	200	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	1.5
120	120	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	2.5	2.0	1.5
	200	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	3.0	3.0	2.5	1.5
		6	7½	9	10½	12	13½	15	18	21	24	30	36	45	60
		FEET SEMI & INDIRECT LIGHTING UNITS—Ceiling Height Above Plane of Work													

TABLE XV—COEFFICIENTS OF UTILIZATION.

Find *Room Index* from Table XIV. Check Reflection Factors, Table VIII

DIRECT LIGHTING VITREOUS ENAMEL REFLECTORS

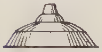
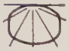
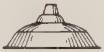
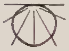
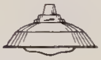
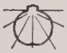
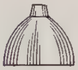
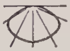
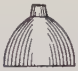
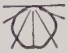
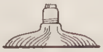
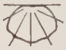
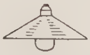
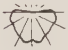
	COLOUR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
1	DISPERSIVE  Clear Lamp 	0.6	.34	.29	.24	.34	.29	.24	.28	.24
		0.8	.42	.38	.34	.42	.37	.33	.37	.33
		1.0	.46	.43	.39	.45	.42	.39	.42	.39
		1.25	.50	.47	.43	.49	.46	.43	.45	.42
		1.5	.53	.50	.46	.52	.49	.46	.48	.45
		2.0	.58	.55	.51	.57	.54	.51	.53	.51
		2.5	.62	.59	.56	.61	.58	.56	.58	.56
		3.0	.64	.61	.58	.63	.60	.58	.60	.58
		4.0	.67	.65	.63	.66	.64	.62	.63	.61
		5.0	.69	.67	.65	.67	.66	.64	.65	.63
2	DISPERSIVE  Bowl-Sprayed Lamp 	0.6	.32	.28	.25	.32	.28	.25	.27	.25
		0.8	.40	.36	.34	.39	.35	.33	.35	.33
		1.0	.43	.39	.37	.42	.39	.37	.39	.37
		1.25	.46	.43	.41	.45	.43	.41	.43	.41
		1.5	.48	.45	.43	.47	.45	.43	.45	.43
		2.0	.52	.50	.48	.51	.49	.47	.49	.47
		2.5	.56	.54	.52	.55	.53	.51	.53	.51
		3.0	.57	.55	.53	.56	.54	.52	.54	.52
		4.0	.60	.58	.56	.59	.57	.55	.57	.55
		5.0	.61	.59	.57	.60	.58	.57	.58	.56
3	REFLECTOR DIFFUSER  	0.6	.29	.25	.21	.28	.24	.21	.23	.21
		0.8	.36	.32	.29	.35	.31	.28	.31	.28
		1.0	.39	.36	.33	.38	.35	.33	.34	.32
		1.25	.42	.39	.36	.41	.38	.36	.37	.35
		1.5	.45	.42	.39	.43	.40	.38	.39	.38
		2.0	.49	.46	.43	.48	.45	.43	.44	.42
		2.5	.53	.50	.47	.51	.49	.47	.47	.46
		3.0	.54	.52	.49	.52	.50	.49	.49	.47
		4.0	.57	.55	.53	.55	.53	.51	.51	.50
		5.0	.58	.56	.54	.56	.54	.53	.52	.51
4	DEEP BOWL  Clear Lamp 	0.6	.31	.26	.23	.30	.26	.23	.25	.23
		0.8	.38	.34	.31	.37	.34	.31	.33	.31
		1.0	.41	.38	.35	.41	.38	.35	.37	.35
		1.25	.44	.41	.38	.44	.41	.38	.40	.38
		1.5	.47	.44	.41	.46	.43	.41	.43	.41
		2.0	.51	.48	.45	.50	.47	.45	.47	.45
		2.5	.54	.51	.49	.53	.51	.49	.51	.49
		3.0	.56	.54	.51	.55	.53	.51	.53	.51
		4.0	.58	.56	.54	.57	.55	.54	.55	.53
		5.0	.60	.58	.56	.58	.57	.55	.56	.55
5	DEEP BOWL  Bowl-Sprayed Lamp 	0.6	.29	.26	.23	.29	.26	.23	.25	.23
		0.8	.35	.33	.31	.35	.32	.30	.32	.30
		1.0	.38	.36	.34	.38	.36	.34	.35	.34
		1.25	.41	.39	.37	.41	.39	.37	.38	.37
		1.5	.44	.41	.39	.43	.41	.39	.40	.39
		2.0	.47	.45	.43	.46	.44	.43	.43	.43
		2.5	.50	.48	.46	.49	.47	.46	.46	.46
		3.0	.51	.49	.47	.50	.48	.47	.47	.47
		4.0	.53	.51	.50	.52	.50	.49	.49	.49
		5.0	.54	.52	.51	.53	.51	.50	.50	.49

TABLE XV—COEFFICIENTS OF UTILIZATION.

Find *Room Index* from Table XIV. Check Reflection Factors, Table VIII

DIRECT LIGHTING VITREOUS ENAMEL REFLECTORS

	COLOUR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (50%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
6	DISTRIBUTING REFLECTOR  	0.6	.34	.29	.25	.33	.29	.25	28	.25
		0.8	.42	.38	.35	.41	.37	.34	.37	.34
		1.0	.45	.42	.39	.45	.42	.39	.41	.39
		1.25	.49	.45	.43	.48	.45	.43	.44	.43
		1.5	.52	.48	.46	.51	.48	.45	.47	.45
		2.0	.56	.53	.51	.56	.53	.51	.52	.51
		2.5	.61	.58	.55	.59	.57	.55	.56	.55
		3.0	.62	.60	.57	.61	.59	.57	.58	.56
		4.0	.65	.63	.61	.64	.61	.60	.61	.59
		5.0	.67	.64	.62	.65	.63	.61	.62	.61
7	ENAMELLED IRON SHADE  Clear Lamp 	0.6	.26	.20	.16	.26	.19	.16	.19	.16
		0.8	.32	.26	.22	.32	.26	.22	.26	.22
		1.0	.36	.30	.26	.36	.30	.26	.30	.26
		1.25	.41	.35	.30	.39	.34	.30	.33	.30
		1.5	.44	.38	.33	.42	.37	.33	.36	.33
		2.0	.50	.44	.38	.48	.43	.38	.42	.38
		2.5	.54	.48	.42	.52	.47	.42	.46	.42
		3.0	.57	.51	.46	.55	.50	.45	.49	.45
		4.0	.62	.56	.51	.60	.54	.50	.53	.50
		5.0	.65	.60	.54	.62	.56	.53	.55	.53

DIRECT LIGHTING OPEN GLASS REFLECTORS

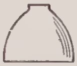
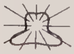
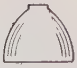
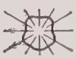
	COLOUR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
8	LIGHT DENSITY OPAL  Clear Lamp 	0.6	.26	.21	.17	.24	.19	.16	.18	.15
		0.8	.32	.27	.23	.30	.25	.22	.24	.21
		1.0	.36	.31	.27	.34	.29	.26	.27	.24
		1.25	.40	.35	.31	.37	.32	.29	.30	.27
		1.5	.44	.38	.34	.40	.35	.32	.32	.30
		2.0	.49	.44	.39	.45	.40	.37	.37	.34
		2.5	.53	.48	.44	.49	.44	.41	.40	.38
		3.0	.56	.51	.47	.51	.46	.43	.42	.40
		4.0	.60	.55	.51	.55	.50	.47	.46	.44
		5.0	.62	.58	.54	.57	.53	.50	.48	.46
9	LIGHT DENSITY OPAL Bowl-sprayed  	0.6	.22	.17	.14	.20	.16	.13	.14	.12
		0.8	.27	.22	.19	.25	.21	.18	.19	.16
		1.0	.31	.26	.23	.28	.24	.21	.22	.19
		1.25	.35	.30	.26	.31	.27	.24	.24	.22
		1.5	.38	.33	.29	.34	.30	.26	.27	.24
		2.0	.43	.38	.34	.38	.34	.31	.30	.28
		2.5	.47	.42	.38	.42	.38	.34	.34	.31
		3.0	.49	.44	.40	.44	.40	.37	.36	.33
		4.0	.53	.49	.45	.48	.44	.41	.39	.37
		5.0	.56	.52	.48	.50	.46	.43	.40	.39

TABLE XV—COEFFICIENTS OF UTILIZATION.

Find *Room Index* from Table XIV. Check Reflection Factors, Table VIII

DIRECT LIGHTING OPEN GLASS REFLECTORS

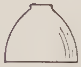
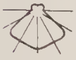
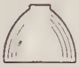
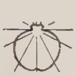
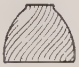
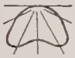
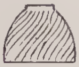
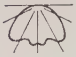
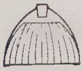
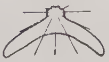
	COLOUR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	'COEFFICIENTS OF UTILIZATION							
10	DENSE OPAL  Clear Lamp 	0.6	.32	.27	.23	.31	.26	.22	.25	.22
		0.8	.40	.35	.31	.38	.34	.31	.33	.30
		1.0	.44	.39	.36	.42	.38	.35	.37	.35
		1.25	.47	.43	.40	.46	.42	.39	.40	.38
		1.5	.51	.47	.43	.49	.45	.42	.43	.41
		2.0	.56	.52	.48	.54	.50	.47	.48	.46
		2.5	.60	.56	.53	.57	.54	.52	.52	.50
		3.0	.63	.59	.55	.60	.56	.54	.54	.52
		4.0	.66	.63	.60	.63	.60	.58	.57	.55
		5.0	.67	.65	.62	.65	.61	.59	.59	.57
11	DENSE OPAL  Bowl-Sprayed Lamp 	0.6	.29	.24	.20	.28	.23	.20	.22	.20
		0.8	.35	.31	.28	.34	.30	.27	.29	.27
		1.0	.39	.35	.32	.38	.34	.32	.33	.31
		1.25	.43	.39	.36	.41	.38	.35	.36	.34
		1.5	.46	.42	.38	.44	.40	.37	.38	.36
		2.0	.51	.47	.44	.48	.45	.42	.43	.41
		2.5	.55	.51	.48	.52	.49	.46	.47	.45
		3.0	.57	.54	.50	.54	.51	.48	.48	.46
		4.0	.60	.57	.54	.57	.54	.52	.51	.50
		5.0	.62	.59	.56	.58	.56	.54	.53	.52
12	MIRRORED GLASS  Clear Lamp 	0.6	.32	.27	.24	.31	.27	.24	.27	.24
		0.8	.39	.35	.32	.39	.35	.32	.35	.32
		1:0	.43	.39	.37	.42	.39	.37	.39	.37
		1.25	.46	.43	.40	.46	.43	.40	.42	.40
		1.5	.49	.46	.43	.48	.45	.43	.45	.43
		2.0	.53	.50	.48	.52	.50	.48	.49	.48
		2.5	.57	.54	.52	.56	.54	.52	.53	.52
		3.0	.58	.56	.54	.57	.55	.54	.54	.53
		4.0	.61	.59	.57	.60	.58	.56	.57	.56
		5.0	.63	.61	.58	.61	.59	.58	.58	.57
13	MIRRORED GLASS  Bowl-Sprayed Lamp 	0.6	.26	.22	.19	.25	.22	.19	.21	.19
		0.8	.32	.29	.26	.31	.28	.26	.28	.26
		1.0	.35	.32	.30	.34	.32	.30	.31	.30
		1.25	.38	.35	.33	.37	.35	.33	.34	.33
		1.5	.40	.37	.35	.39	.37	.35	.36	.35
		2.0	.43	.41	.39	.42	.40	.39	.40	.39
		2.5	.46	.44	.42	.45	.43	.42	.43	.42
		3.0	.47	.46	.44	.46	.45	.44	.44	.43
		4.0	.49	.48	.46	.48	.47	.46	.46	.45
		5.0	.50	.49	.47	.49	.48	.47	.47	.46
14	PRISMATIC INDUSTRIAL  Clear Lamp 	0.6	.33	.26	.21	.31	.25	.21	.24	20
		0.8	.41	.35	.30	.39	.33	.29	.32	29
		1.0	.45	.40	.35	.43	.39	.34	.37	33
		1.25	.50	.44	.39	.47	.42	.38	.40	37
		1.5	.52	.48	.43	.50	.45	.42	.43	40
		2.0	.58	.54	.49	.56	.51	.47	.49	46
		2.5	.63	.59	.54	.60	.56	.53	.54	51
		3.0	.66	.62	.58	.63	.59	.56	.56	54
		4.0	.71	.67	.63	.67	.63	.61	.60	58
		5.0	.73	.69	.66	.69	.65	.63	.62	60

TABLE XV—COEFFICIENTS OF UTILIZATION.

Find *Room Index* from Table XIV. Check Reflection Factors, Table VIII

DIRECT LIGHTING ENCLOSING AND SEMI-ENCLOSING UNITS

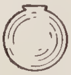
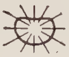
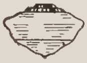
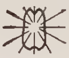
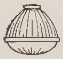
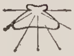
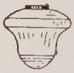
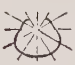
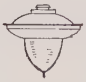
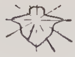
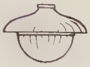
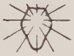
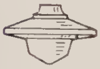
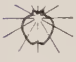
	COLOUR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
15	DIFFUSING GLOBE Light Opal	0.6	.18	.13	.10	.16	.12	.10	.10	.09
		0.8	.22	.17	.14	.20	.16	.13	.14	.12
		1.0	.26	.21	.18	.23	.19	.16	.17	.14
		1.25	.29	.24	.21	.26	.22	.19	.19	.16
		1.5	.32	.27	.23	.29	.24	.21	.22	.19
		2.0	.37	.32	.28	.32	.28	.25	.25	.22
		2.5	.40	.35	.31	.35	.31	.28	.28	.25
		3.0	.43	.38	.34	.38	.33	.30	.30	.27
		4.0	.47	.42	.38	.41	.37	.34	.33	.31
		5.0	.49	.45	.41	.43	.39	.36	.34	.33
16	ONE-PIECE OPAL Flattened Reflecting Top	0.6	.22	.17	.14	.20	.16	.13	.14	.12
		0.8	.27	.22	.19	.25	.21	.18	.19	.17
		1.0	.31	.26	.23	.28	.24	.21	.22	.19
		1.25	.35	.30	.26	.31	.27	.24	.25	.22
		1.5	.38	.33	.29	.34	.30	.27	.27	.24
		2.0	.42	.38	.33	.38	.34	.31	.31	.28
		2.5	.46	.41	.37	.41	.37	.34	.34	.31
		3.0	.49	.45	.40	.43	.39	.36	.36	.33
		4.0	.53	.48	.44	.47	.43	.40	.38	.36
		5.0	.55	.51	.47	.49	.45	.42	.40	.38
17	PRISMATIC ENCLOSING	0.6	.28	.22	.18	.26	.21	.17	.19	.16
		0.8	.35	.29	.25	.33	.28	.24	.26	.23
		1.0	.38	.33	.29	.36	.32	.28	.30	.27
		1.25	.43	.37	.33	.40	.35	.31	.33	.30
		1.5	.46	.41	.36	.43	.38	.34	.35	.33
		2.0	.51	.46	.42	.47	.43	.40	.40	.38
		2.5	.55	.51	.46	.51	.47	.44	.44	.42
		3.0	.58	.54	.50	.54	.50	.47	.46	.44
		4.0	.62	.58	.55	.57	.54	.51	.50	.48
		5.0	.65	.61	.57	.60	.56	.53	.52	.50
18	DEEP DIFFUSING	0.6	.18	.13	.10	.16	.12	.10	.11	.09
		0.8	.22	.18	.15	.21	.16	.14	.15	.13
		1.0	.25	.21	.18	.23	.19	.17	.18	.15
		1.25	.29	.24	.21	.26	.22	.19	.20	.17
		1.5	.32	.27	.23	.28	.24	.21	.22	.20
		2.0	.36	.31	.27	.32	.28	.25	.25	.23
		2.5	.39	.34	.31	.35	.31	.28	.28	.25
		3.0	.41	.37	.33	.37	.33	.30	.30	.28
		4.0	.45	.41	.37	.40	.36	.34	.33	.31
		5.0	.47	.43	.40	.42	.38	.36	.34	.33
19	ONE-PIECE GLASS	0.6	.22	.17	.14	.21	.16	.14	.15	.14
		0.8	.27	.23	.20	.26	.22	.19	.20	.18
		1.0	.30	.26	.23	.29	.25	.22	.23	.21
		1.25	.34	.30	.26	.32	.28	.25	.26	.24
		1.5	.37	.33	.29	.34	.30	.27	.28	.26
		2.0	.41	.37	.33	.38	.34	.31	.32	.30
		2.5	.44	.40	.36	.41	.38	.35	.35	.33
		3.0	.47	.43	.39	.43	.40	.37	.37	.35
		4.0	.51	.47	.43	.47	.44	.41	.41	.39
		5.0	.53	.49	.45	.48	.45	.42	.42	.40

TABLE XV—COEFFICIENTS OF UTILIZATION.

Find *Room Index* from Table XIV. Check Reflection Factors, Table VIII

DIRECT LIGHTING ENCLOSING AND SEMI-ENCLOSING UNITS

	COLOUR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT(50%)	FAIRLY DARK(30%)	VERY DARK(10%)	FAIRLY LIGHT(50%)	FAIRLY DARK(30%)	VERY DARK(30%)	FAIRLY DARK(10%)	VERY DARK(10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
20	TWO-PIECE GLASS  	0.6	.20	.15	.13	.18	.14	.12	.13	.11
		0.8	.25	.20	.17	.23	.19	.16	.18	.15
		1.0	.28	.24	.21	.26	.22	.19	.20	.17
		1.25	.32	.27	.24	.28	.25	.22	.22	.20
		1.5	.34	.30	.26	.31	.27	.24	.25	.22
		2.0	.39	.34	.31	.35	.31	.28	.28	.25
		2.5	.42	.38	.34	.38	.34	.31	.31	.29
		3.0	.44	.40	.37	.40	.36	.33	.33	.30
		4.0	.48	.44	.41	.43	.39	.37	.35	.33
		5.0	.50	.46	.43	.45	.41	.39	.37	.35
21	ONE-PIECE GLASS Enamelled Reflector and Bowl  	0.6	.22	.17	.14	.21	.16	.14	.15	.14
		0.8	.27	.23	.20	.26	.22	.19	.20	.18
		1.0	.30	.26	.23	.29	.25	.22	.23	.21
		1.25	.34	.30	.26	.32	.28	.25	.26	.24
		1.5	.37	.33	.29	.34	.30	.27	.28	.26
		2.0	.41	.37	.33	.38	.34	.31	.32	.30
		2.5	.44	.40	.36	.41	.38	.35	.35	.33
		3.0	.47	.43	.39	.43	.40	.37	.37	.35
		4.0	.51	.47	.43	.47	.44	.41	.41	.39
		5.0	.53	.49	.45	.48	.45	.42	.42	.40

SEMI-INDIRECT AND INDIRECT LIGHTING UNITS

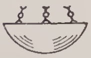
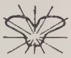
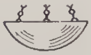
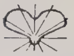
	COLOUR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (30%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT(50%)	FAIRLY DARK(30%)	VERY DARK(10%)	FAIRLY LIGHT(50%)	FAIRLY DARK(30%)	VERY DARK(10%)	FAIRLY DARK(30%)	VERY DARK(10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
22	LIGHT OPAL  	0.6	.18	.14	.11	.15	.12	.09	.09	.07
		0.8	.22	.18	.15	.19	.15	.12	.12	.10
		1.0	.26	.22	.18	.22	.18	.15	.14	.12
		1.25	.30	.25	.22	.25	.21	.18	.16	.14
		1.5	.33	.28	.24	.27	.23	.20	.18	.16
		2.0	.38	.33	.29	.31	.27	.24	.21	.19
		2.5	.41	.36	.32	.34	.30	.27	.24	.22
		3.0	.44	.39	.35	.36	.32	.29	.25	.23
		4.0	.49	.44	.40	.40	.36	.33	.28	.26
		5.0	.51	.46	.42	.42	.38	.35	.29	.28
23	DENSE OPAL or Light Opal and Bowl-Sprayed Lamp  	0.6	.16	.13	.11	.12	.10	.08	.07	.06
		0.8	.20	.17	.15	.16	.13	.11	.09	.08
		1.0	.23	.20	.17	.18	.15	.13	.10	.09
		1.25	.27	.23	.20	.21	.18	.16	.12	.11
		1.5	.29	.26	.22	.23	.19	.17	.13	.12
		2.0	.33	.29	.26	.26	.22	.20	.15	.14
		2.5	.36	.32	.29	.28	.25	.23	.17	.16
		3.0	.39	.35	.32	.29	.27	.25	.18	.17
		4.0	.43	.39	.36	.32	.30	.28	.20	.19
		5.0	.45	.41	.38	.34	.32	.30	.22	.20

TABLE XV—COEFFICIENTS OF UTILIZATION.

Find *Room Index* from Table XIV. Check Reflection Factors, Table VIII

SEMI-INDIRECT AND INDIRECT LIGHTING UNITS

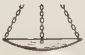
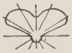
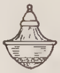
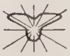
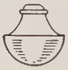
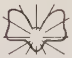
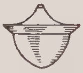
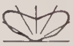
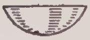
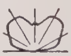
	COLOUR REFLECTION FACTOR	CEILING	VERY LIGHT (70%)			FAIRLY LIGHT (50%)			FAIRLY DARK (30%)	
		WALLS	FAIRLY LIGHT (50%)	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY LIGHT (50%	FAIRLY DARK (30%)	VERY DARK (10%)	FAIRLY DARK (30%)	VERY DARK (10%)
	REFLECTOR TYPE	ROOM INDEX	COEFFICIENTS OF UTILIZATION							
24	ALABASTER BOWL  	0.6	.15	.12	.10	.11	.10	.08	.07	.06
		0.8	.18	.15	.13	.14	.12	.10	.08	.08
		1.0	.21	.18	.16	.16	.14	.12	.09	.09
		1.25	.24	.21	.18	.19	.16	.14	.10	.09
		1.5	.26	.23	.20	.20	.17	.15	.11	.10
		2.0	.29	.27	.24	.23	.20	.18	.13	.12
		2.5	.32	.29	.27	.24	.22	.21	.14	.14
		3.0	.34	.31	.29	.26	.24	.22	.15	.14
		4.0	.38	.35	.32	.28	.27	.25	.17	.16
		5.0	.39	.36	.35	.29	.28	.27	.18	.17
25	PRISMATIC ENCLOSED  	0.6	.19	.15	.12	.16	.13	.10	.10	.09
		0.8	.24	.20	.17	.20	.17	.14	.14	.12
		1.0	.27	.23	.20	.23	.19	.17	.16	.14
		1.25	.31	.27	.23	.26	.22	.20	.18	.16
		1.5	.34	.29	.25	.28	.24	.22	.20	.18
		2.0	.38	.34	.30	.32	.28	.25	.22	.20
		2.5	.41	.37	.34	.34	.31	.28	.25	.23
		3.0	.44	.40	.36	.36	.33	.30	.26	.24
		4.0	.48	.44	.41	.40	.36	.34	.29	.27
		5.0	.50	.46	.43	.42	.38	.36	.30	.29
26	CLEAR TOP ENCLOSED Enamelled Glass  	0.6	.16	.12	.10	.13	.10	.08	.07	.06
		0.8	.20	.16	.13	.17	.13	.11	.10	.09
		1.0	.23	.19	.16	.19	.15	.13	.12	.10
		1.25	.26	.22	.19	.21	.18	.15	.14	.12
		1.5	.29	.25	.21	.24	.20	.17	.15	.13
		2.0	.32	.28	.25	.26	.23	.20	.18	.16
		2.5	.36	.31	.28	.29	.26	.23	.20	.18
		3.0	.38	.34	.31	.31	.28	.25	.22	.20
		4.0	.42	.38	.35	.34	.31	.29	.24	.22
		5.0	.44	.40	.37	.36	.33	.31	.25	.24
27	MIRRORED INDIRECT  	0.6	.15	.12	.10	.11	.09	.07	.05	.04
		0.8	.18	.15	.13	.13	.11	.09	.07	.06
		1.0	.22	.19	.16	.15	.13	.11	.08	.07
		1.25	.25	.22	.19	.18	.15	.13	.09	.08
		1.5	.27	.24	.21	.20	.17	.15	.10	.09
		2.0	.30	.27	.25	.22	.19	.17	.11	.10
		2.5	.34	.31	.28	.24	.22	.20	.13	.12
		3.0	.36	.33	.30	.26	.24	.22	.14	.13
		4.0	.40	.37	.34	.28	.26	.24	.15	.14
		5.0	.42	.39	.37	.30	.28	.26	.17	.15
28	ENAMELLED METAL INDIRECT  	0.6	.14	.11	.10	.10	.08	.07	.04	.04
		0.8	.17	.14	.13	.13	.10	.09	.06	.05
		1.0	.20	.17	.15	.14	.12	.10	.07	.06
		1.25	.23	.20	.17	.17	.14	.13	.08	.07
		1.5	.25	.22	.19	.18	.15	.14	.09	.08
		2.0	.28	.25	.23	.21	.18	.16	.10	.10
		2.5	.31	.28	.26	.22	.20	.18	.12	.11
		3.0	.33	.30	.28	.24	.22	.20	.13	.12
		4.0	.37	.34	.32	.26	.24	.22	.14	.13
		5.0	.39	.36	.34	.28	.26	.24	.15	.14

TABLE XVI

LUMENS RATINGS AND DIMENSIONS OF GAS-FILLED LAMPS, as per B.E.S.A. Specification No. 161—1924

Rating		Approx. Rated Lumens	Maximum Over-all Dimensions						Light Centre Length with Standard Cap Tolerance ± 10% with max. of 10 mm.		Standard Caps
High Voltage	Low Voltage		Length		Diameter of Bulb		Diameter of Neck				
200-260	100-130		mm.	inches	mm.	inches	mm.	inches	mm.	inches	
	30	275	120	4·7	62	2·4	35	1·4	80	3·2	B.C.
40		305	125	4·9	62	2·4	35	1·4	85	3·4	,,
	40	390	,,	,,	,,	,,	,,	,,	,,	,,	,,
60		545	125	4·9	72	2·8	40	1·6	85	3·4	,,
	60	660	,,	,,	,,	,,	,,	,,	,,	,,	,,
75		750	150	6·0	72	2·8	40	1·6	100	4·0	,,
	75	875	,,	,,	,,	,,	,,	,,	,,	,,	,,
100		1,100	170	6·7	82	3·2	42	1·7	120	4·8	,,
	100	1,250	,,	,,	,,	,,	,,	,,	,,	,,	,,
150		1,720	170	6·7	9·2	3·6	45	1·8	120	4·8	B.C. or E.S.
	150	1,970	180	7·1	92	3·6	45	1·8	130	5·2	
200		2,510	215	8·5	103	4·1	48	1·9	150	5·9	E.S.
	200	2,730	,,	,,	,,	,,	,,	,,	,,	,,	,,
300		3,930	250	9·9	113	4·5	55	2·2	180	7·1	G.E.S.
	300	4,260	,,	,,	,,	,,	,,	,,	,,	,,	,,
500		7,110	280	11·1	133	5·3	60	2·4	205	8·1	,,
	500	8,000	,,	,,	,,	,,	,,	,,	,,	,,	,,
1,000		16,000	340	13·4	173	6·8	70	2·8	250	9·9	,,
	1,000	17,100	,,	,,	,,	,,	,,	,,	,,	,,	,,
1,500		24,830	340	13·4	173	6·8	70	2·8	250	9·9	,,
	1,500	25,700	,,	,,	,,	,,	,,	,,	,,	,,	,,

OTHER STANDARD TYPES OF GAS-FILLED LAMPS

Type	Sizes
Opal or white-sprayed . . .	Standard sizes up to 500-watt
Bowl sprayed	Standard sizes up to 500-watt
Coloured-sprayed . . . . . . Colours:—Red, Blue, Green, Amber, Yellow, Flame, and Ivory.	Standard sizes up to 200-watt
Daylight	Standard sizes up to 500-watt

TABLE XVII

COMPUTED ILLUMINATION VALUES

Using Depreciation Factor of 1.3.

Area in Sq.Ft. per Lamp	Size of Lamp 200-260 Volts		COEFFICIENT OF UTILIZATION															
	Rated Watts	Average Initial Lumens	14	16	18	20	22	25	28	32	36	40	45	50	55	60	65	70
			FOOT CANDLES															
60	100	1100	2.0	2.3	2.5	2.8	3.1	3.5	3.9	4.5	5.1	5.6	6.3	7.0	7.7	8.5	9.2	9.9
	150	1720	3.1	3.5	4.0	4.4	4.8	5.5	6.2	7.0	7.9	8.8	9.9	11.0	12.1	13.2	14.3	15.4
	200	2510	4.5	5.1	5.8	6.4	7.1	8.0	9.0	10.3	11.6	12.9	14.5	16.1	17.7	19.3	20.9	22.5
	300	3930	7.1	8.1	9.1	10.1	11.1	12.6	14.1	16.1	18.1	20.2	22.7	25.2	27.7	30.2	32.7	35.2
70	100	1100	1.7	1.9	2.2	2.4	2.7	3.0	3.4	3.9	4.4	4.8	5.4	6.0	6.7	7.3	7.9	8.5
	150	1720	2.6	3.0	3.4	3.8	4.1	4.7	5.3	6.0	6.8	7.5	8.5	9.4	10.4	11.3	12.2	13.2
	200	2510	3.9	4.4	5.0	5.5	6.1	6.9	7.7	8.8	9.9	11.0	12.4	13.8	15.2	16.5	17.9	19.3
	300	3930	6.0	6.9	7.8	8.6	9.5	10.8	12.1	13.8	15.5	17.3	19.4	21.6	23.7	25.9	28.1	30.2
80	100	1100	1.5	1.7	1.9	2.1	2.3	2.6	3.0	3.4	3.8	4.2	4.8	5.3	5.8	6.3	6.9	7.4
	150	1720	2.3	2.6	3.0	3.3	3.6	4.1	4.6	5.3	5.9	6.6	7.4	8.2	9.1	9.9	10.7	11.5
	200	2510	3.4	3.8	4.3	4.8	5.3	6.0	6.7	7.7	8.7	9.6	10.8	12.0	13.2	14.5	15.6	16.8
	300	3930	5.3	6.0	6.8	7.6	8.3	9.5	10.6	12.1	13.6	15.1	17.0	18.9	20.8	22.7	24.5	26.5
90	100	1100	1.3	1.5	1.7	1.9	2.1	2.4	2.6	3.0	3.4	3.8	4.2	4.7	5.2	5.6	6.1	6.6
	150	1720	2.0	2.3	2.6	2.9	3.2	3.7	4.1	4.7	5.3	5.9	6.6	7.3	8.1	8.8	9.5	10.2
	200	2510	3.0	3.4	3.8	4.3	4.7	5.3	6.0	6.8	7.7	8.5	9.6	10.7	11.7	12.8	13.9	14.9
	300	3930	4.7	5.4	6.0	6.7	7.4	8.4	9.4	10.7	12.1	13.4	15.1	16.8	18.5	20.1	21.8	23.5
100	100	1100	1.2	1.4	1.5	1.7	1.9	2.1	2.4	2.7	3.0	3.4	3.8	4.2	4.6	5.1	5.5	5.9
	150	1720	1.8	2.1	2.4	2.6	2.9	3.3	3.7	4.2	4.7	5.3	5.9	6.6	7.2	7.9	8.6	9.2
	200	2510	2.7	3.1	3.5	3.9	4.2	4.8	5.4	6.2	6.9	7.7	8.7	9.6	10.6	11.6	12.5	13.5
	300	3930	4.2	4.8	5.4	6.0	6.7	7.6	8.5	9.7	10.9	12.1	13.6	15.1	16.6	18.1	19.6	21.2
110	100	1100	1.1	1.2	1.4	1.5	1.7	1.9	2.2	2.5	2.8	3.1	3.5	3.8	4.2	4.6	5.0	5.4
	150	1720	1.7	1.9	2.2	2.4	2.6	3.0	3.4	3.8	4.3	4.8	5.4	6.0	6.6	7.2	7.8	8.4
	200	2510	2.5	2.8	3.2	3.5	3.9	4.4	4.9	5.6	6.3	7.0	7.9	8.7	9.6	10.5	11.4	12.2
	300	3930	3.8	4.4	4.9	5.5	6.0	6.9	7.7	8.8	9.9	11.0	12.4	13.7	15.1	16.5	17.9	19.2

Note:–The above figures are for Lamps of 200-260 Volts.
For low voltage supply (100–130) multiply all above by 1.1.

TABLE XVII *Continued*

Area in Sq.Ft. per Lamp	Size of Lamp 200-260 Volts		COEFFICIENT OF UTILIZATION															
	Rated Watts	Average Initial Lumens	.14	.16	.18	.20	.22	.25	.28	.32	.36	.40	.45	.50	.55	.60	.65	.70
			FOOT CANDLES															
120	100	1100	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.3	2.5	2.8	3.2	3.5	3.9	4.2	4.6	4.9
	150	1700	1.5	1.8	2.0	2.2	2.4	2.7	3.1	3.5	4.0	4.4	4.9	5.5	6.0	6.6	7.1	7.7
	200	2510	2.2	2.6	2.9	3.2	3.5	4.0	4.5	5.1	5.8	6.4	7.2	8.0	8.8	9.6	10.5	11.2
	300	3930	3.5	4.0	4.5	5.0	5.5	6.3	7.1	8.1	9.1	10.1	11.3	12.6	13.9	15.1	16.4	17.6
130	100	1100	0.9	1.0	1.2	1.3	1.4	1.6	1.8	2.1	2.3	2.6	2.9	3.3	3.6	3.9	4.2	4.6
	150	1720	1.4	1.6	1.8	2.0	2.2	2.5	2.8	3.2	3.7	4.1	4.6	5.1	5.6	6.1	6.6	7.1
	200	2510	2.1	2.4	2.7	3.0	3.3	3.7	4.1	4.7	5.3	5.9	6.7	7.4	8.1	8.9	9.6	10.4
	300	3930	3.3	3.7	4.2	4.7	5.1	5.8	6.5	7.4	8.4	9.3	10.5	11.6	12.8	14.0	15.1	16.3
140	100	1100	0.8	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.3	3.6	3.9	4.2
	150	1720	1.3	1.5	1.7	1.9	2.1	2.4	2.6	3.0	3.4	3.8	4.2	4.7	5.2	5.6	6.1	6.6
	200	2510	1.9	2.2	2.5	2.7	3.0	3.4	3.9	4.4	4.9	5.5	6.2	6.9	7.6	8.3	8.9	9.6
	300	3930	3.0	3.5	3.9	4.3	4.7	5.4	6.0	6.9	7.8	8.6	9.7	10.8	11.9	13.0	14.0	15.1
160	150	1720	1.2	1.3	1.5	1.6	1.8	2.1	2.3	2.6	3.0	3.3	3.7	4.1	4.5	4.9	5.4	5.8
	200	2510	1.7	1.9	2.2	2.4	2.6	3.0	3.4	3.9	4.3	4.8	5.4	6.0	6.6	7.2	7.8	8.4
	300	3930	2.6	3.0	3.4	3.8	4.2	4.7	5.3	6.0	6.8	7.6	8.5	9.5	10.4	11.4	12.3	13.2
	500	7110	4.8	5.5	6.1	6.8	7.5	8.5	9.5	10.9	12.3	13.7	15.4	17.1	18.8	20.5	22.2	23.9
180	150	1720	1.0	1.2	1.3	1.5	1.6	1.8	2.0	2.3	2.6	2.9	3.3	3.7	4.0	4.4	4.8	5.1
	200	2510	1.5	1.7	1.9	2.1	2.4	2.7	3.0	3.4	3.8	4.3	4.8	5.3	5.9	6.4	6.9	7.5
	300	3930	2.4	2.7	3.0	3.4	3.7	4.2	4.7	5.4	6.0	6.7	7.6	8.4	9.2	10.1	10.9	11.8
	500	7110	4.2	4.9	5.5	6.1	6.7	7.6	8.5	9.7	10.9	12.1	13.7	15.2	16.7	18.2	19.7	21.2
200	150	1720	0.9	1.1	1.2	1.3	1.5	1.7	1.8	2.1	2.4	2.6	3.0	3.3	3.6	4.0	4.3	4.6
	200	2510	1.3	1.5	1.7	1.9	2.1	2.4	2.7	3.1	3.5	3.8	4.3	4.8	5.3	5.8	6.2	6.7
	300	3930	2.1	2.4	2.7	3.0	3.3	3.8	4.2	4.8	5.4	6.0	6.8	7.6	8.3	9.1	9.8	10.6
	500	7110	3.8	4.4	4.9	5.5	6.0	6.8	7.6	8.7	9.8	10.9	12.3	13.7	15.0	16.4	17.8	19.1
220	150	1720	0.8	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.3	3.6	3.9	4.2
	200	2510	1.2	1.4	1.6	1.7	1.9	2.2	2.4	2.8	3.1	3.5	3.9	4.4	4.8	5.2	5.7	6.1
	300	3930	1.9	2.2	2.5	2.7	3.0	3.4	3.8	4.4	4.9	5.5	6.2	6.9	7.6	8.2	8.9	9.6
	500	7110	3.5	4.0	4.5	5.0	5.5	6.2	7.0	7.9	8.9	9.9	11.2	12.4	13.7	14.9	16.1	17.4

Note:—The above figures are for Lamps of 200-260 Volts.
For low voltage supply (100-130) multiply all above by 1.1.

TABLE XVII *Continued*

Area in Sq. Ft per Lamp	Size of lamp 200-260 Volts		COEFFICIENT OF UTILIZATION															
	Rated Watts	Average Initial Lumens	.14	.16	.18	.20	.22	.25	.28	.32	.36	.40	.45	.50	.55	.60	.65	.70
			FOOT CANDLES															
250	200	2510	1.1	1.2	1.4	1.5	1.7	1.9	2.2	2.5	2.8	3.1	3.5	3.8	4.2	4.6	5.0	5.4
	300	3930	1.7	1.9	2.2	2.4	2.7	3.0	3.4	3.9	4.4	4.8	5.4	6.0	6.7	7.3	7.9	8.5
	500	7110	3.1	3.5	3.9	4.4	4.8	5.5	6.1	7.0	7.9	8.7	9.8	10.9	12.0	13.1	14.2	15.3
280	200	2510	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.2	2.5	2.7	3.1	3.4	3.8	4.1	4.5	4.8
	300	3930	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.5	3.9	4.3	4.9	5.4	5.9	6.5	7.0	7.6
	500	7110	2.7	3.1	3.5	3.9	4.3	4.9	5.5	6.2	7.0	7.8	8.8	9.8	10.7	11.7	12.7	13.7
320	200	2510	0.8	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.3	3.6	3.9	4.2
	300	3930	1.3	1.5	1.7	1.9	2.1	2.4	2.6	3.0	3.4	3.8	4.3	4.7	5.2	5.7	6.1	6.6
	500	7110	2.4	2.7	3.1	3.4	3.8	4.3	4.8	5.5	6.1	6.8	7.7	8.5	9.4	10.2	11.1	12.0
360	200	2510	0.7	0.9	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.1	2.4	2.7	2.9	3.2	3.5	3.7
	300	3930	1.2	1.3	1.5	1.7	1.8	2.1	2.3	2.7	3.0	3.4	3.8	4.2	4.6	5.0	5.5	5.9
	500	7110	2.1	2.4	2.7	3.0	3.3	3.8	4.2	4.9	5.5	6.1	6.8	7.6	8.3	9.1	9.9	10.6
400	200	2510	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.2	2.4	2.6	2.9	3.1	3.4
	300	3930	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.4	2.7	3.0	3.4	3.8	4.2	4.5	4.9	5.3
	500	7110	1.9	2.2	2.5	2.7	3.0	3.4	3.8	4.4	4.9	5.5	6.1	6.8	7.5	8.2	8.9	9.6
450	200	2510	0.6	0.7	0.8	0.9	0.9	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.4	2.6	2.8	3.0
	300	3930	0.9	1.1	1.2	1.3	1.5	1.7	1.9	2.1	2.4	2.7	3.0	3.4	3.7	4.0	4.4	4.7
	500	7110	1.7	2.9	2.2	2.4	2.7	3.0	3.4	3.9	4.4	4.9	5.5	6.1	6.7	7.3	7.9	8.5
500	300	3930	0.8	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.3	3.6	3.9	4.2
	500	7110	1.5	1.7	2.0	2.2	2.4	2.7	3.1	3.5	3.9	4.4	4.9	5.5	6.0	6.6	7.1	7.6
	1000	16000	3.5	4.0	4.5	4.9	5.4	6.2	6.9	7.9	8.9	9.9	11.1	12.3	13.5	14.8	16.0	17.2
600	300	3930	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5
	500	7110	1.3	1.5	1.6	1.8	2.0	2.3	2.6	2.9	3.3	3.6	4.1	4.6	5.0	5.5	5.9	6.4
	1000	16000	2.9	3.3	3.7	4.1	4.5	5.1	5.7	6.6	7.4	8.2	9.2	10.3	11.3	12.3	13.3	14.4

Note:—The above figures are for Lamps of 200-260 Volts.
For low voltage supply (100-130) multiply all above by 1.1.

TABLE XVII *Continued*

Area in Sq.Ft. per Lamp	Size of Lamp 200-260 Volts		COEFFICIENT OF UTILIZATION															
	Rated Watts	Average Initial Lumens	.14	.16	.18	.20	.22	.25	.28	.32	.36	.40	.45	.50	.55	.60	.65	.70
			FOOT CANDLES															
700	300	3930	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.6	1.7	1.9	2.2	2.4	2.6	2.8	3.0
	500	7110	1.1	1.2	1.4	1.6	1.7	2.0	2.2	2.5	2.8	3.1	3.5	3.9	4.3	4.7	5.1	5.5
	1000	16000	2.5	2.8	3.2	3.5	3.9	4.4	4.9	5.6	6.3	7.0	7.9	8.8	9.7	10.5	11.4	12.3
800	300	3930	0.5	0.6	0.7	0.8	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.3	2.5	2.6
	500	7110	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.2	2.5	2.7	3.1	3.4	3.8	4.1	4.4	4.8
	1000	16000	2.2	2.5	2.8	3.1	3.4	3.8	4.3	4.9	5.5	6.2	6.9	7.7	8.5	9.2	10.0	10.8
900	300	3930	0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.4
	500	7110	0.9	1.0	1.1	1.2	1.3	1.5	1.7	1.9	2.2	2.4	2.7	3.0	3.3	3.6	3.9	4.2
	1000	16000	1.9	2.2	2.5	2.7	3.0	3.4	3.8	4.4	4.9	5.5	6.2	6.8	7.5	8.2	8.9	9.6
1000	300	3930	0.4	0.5	0.5	0.6	0.7	0.8	0.8	1.0	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1
	500	7110	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.7	2.0	2.2	2.5	2.7	3.0	3.3	3.5	3.8
	1000	16000	1.7	2.0	2.2	2.5	2.7	3.1	3.4	3.9	4.4	4.9	5.5	6.2	6.8	7.4	8.0	8.6
1200	300	3930	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.8
	500	7110	0.6	0.7	0.8	0.9	1.0	1.1	1.3	1.5	1.6	1.8	2.0	2.3	2.5	2.7	3.0	3.2
	1000	16000	1.4	1.6	1.8	2.1	2.3	2.6	2.9	3.3	3.7	4.1	4.6	5.1	5.6	6.2	6.7	7.2
1400	300	3930	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	500	7110	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.6	1.8	2.0	2.1	2.3	2.5	2.7
	1000	16000	1.2	1.4	1.6	1.8	1.9	2.2	2.5	2.8	3.2	3.5	4.0	4.4	4.8	5.3	5.7	6.2
1600	300	3930	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.3
	500	7110	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4
	1000	16000	1.1	1.2	1.4	1.5	1.7	1.9	2.2	2.5	2.8	3.1	3.5	3.8	4.2	4.6	5.0	5.4
2000	300	3930	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.1
	500	7110	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.6	1.8	1.9
	1000	16000	0.9	1.0	1.1	1.2	1.4	1.5	1.7	2.0	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3
2500	300	3930	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8
	500	7110	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	1000	16000	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.6	1.8	2.0	2.2	2.5	2.7	3.0	3.2	3.5

Note:—The above figures are for Lamps of 200-260 Volts.
For low voltage supply (100-130) multiply all above by 1.1.

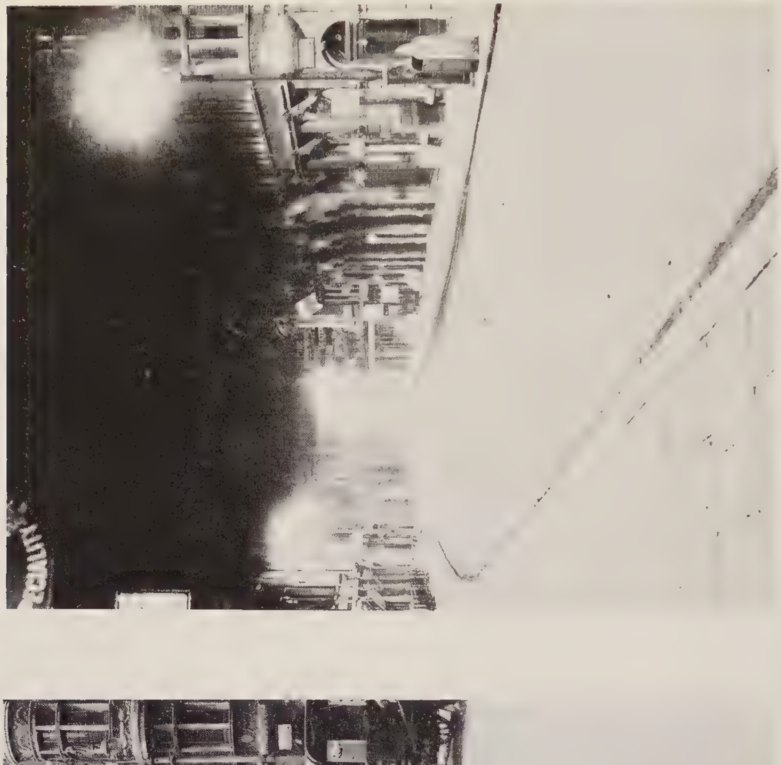


Fig. 97.—An Excellent Example of Up-to-date Street Lighting. The two photographs reproduced were taken at mid-day and midnight respectively upon the same date,

CHAPTER V

STREET LIGHTING

Introduction—General Considerations—Available Systems—Available Methods—Switching—Cleaning and Re-lamping—Illumination required—Diversity Factor—Grading of Streets—Height of Light Sources—Spacing-Height Ratio—Lamps—Lanterns—Methods of Light Control—Influence of Size and Shape of Lamp Filament—Glare—Testing of Installations—Maintenance—Whole and Half Night Lighting—Conversion of Gas Lamps—Signal Lanterns and Illuminated Road Signs.

Introduction.—The lighting of public thoroughfares dates from times considerably more remote than is generally realized. The first recorded organized attempt appears to have been that made in the year 1416, when Sir Henry Burton, the then Lord Mayor of London, required householders to hang out lanthorns on winter evenings between November 1st and January 2nd.

Towards the close of the seventeenth century every householder was compelled to place out a candle or other light on moonless nights, 'excepting such as shall jointly agree to make use of lamps of any sort placed at such distances in the streets as shall be approved by the Justices of the Peace.'

About this time, also, the exclusive right of lighting the streets of London was granted to one Edward Hemming. This privilege was, however, withdrawn in the year 1716, when the onus was again placed upon the individual householders.

The birth of public street lighting as we know it to-day took place in the year 1836, when, owing to the increasing prevalence of street robberies, the Council of the City of London was authorized to erect and maintain street lamps to burn from sunset to sunrise. The keenness of the Council in the exercise of its duties in this direction, and the appreciation, by the public whom it served, of the greatly increased security and comfort thus obtained, is strikingly demonstrated by the fact that in two years the number of such lamps had increased from 5,000 to 15,000, and the hours of burning from 800 to 5,000 per annum.

From this time on, progress in the lighting of the more important cities was distinctly marked, and improvements in both the equipment used and the methods employed followed in comparatively rapid succession.

With the passage of time, however, the older illuminants were gradually ousted from the field by others less costly to maintain and more efficient.

In the realm of electricity, with which we are more particularly concerned, the original pure-carbon arc lamp, with its hissing, spluttering, and frequent periods of almost total extinction, was followed by later patterns in which improvements were gradually introduced. These in turn gave place to the enclosed arc, the flame arc, the magazine arc, and the enclosed long-burning flame arc, each of which, whilst representing, in the best of the various examples, an advance on its predecessors, required, in common, the provision of constant supplies of comparatively costly carbons, and, at frequent intervals, considerable and regular attention in the matter of cleaning and trimming.

Concurrently with these developments, the carbon-filament incandescent lamp of early days was followed by the tantalum lamp, which in its turn gave place to the tungsten-filament vacuum lamp. The latter is now very rapidly being superseded by the tungsten-filament gas-filled lamp, which, owing to its remarkably high efficiency as a light-producing unit, its robust constitution, and its general freedom from trouble, has probably rendered greater service to the cause of better lighting in general than any other single introduction of our time.

It is this lamp which has made possible the enormous improvements in street lighting which are now almost everywhere taking place, with which the future of public lighting as a whole is indissolubly bound up, and to the further progressive development of which alone, we, in the opinion not only of the authors, but of the majority of those best qualified to judge, must of necessity look forward when envisaging the more ample, more perfect, more efficient, and less costly illumination of our streets and thoroughfares in the days to come.

General Considerations.—The problem of the provision and maintenance of adequate and efficient public lighting is happily now receiving the increasing recognition which its complexity and importance undoubtedly merit.

The ever-growing appreciation of the manifold benefits conferred by well-illuminated streets, and the extent to which the question of the securing of such is being forced upon the attention of the municipalities and public authorities concerned, is strikingly exemplified by the appointment in many large cities of a qualified lighting superintendent, who has under his control, and is responsible for the care of, the whole of the public lighting, and in the inauguration of the Institution of Public Lighting Engineers, which amongst other activities holds annually a special conference for the consideration of matters, and the discussion of problems, appertaining to street lighting.

The phenomenal growth in the volume of rapidly moving vehicular traffic in the past few years—to say nothing of its vastly accelerated speed—has still further complicated an already very difficult situation, and practically every city in the country is now confronted with the problem of the revision of its street lighting in such manner as to provide what is now universally looked upon as an essential factor in the safety, comfort, and convenience of the community.

The relation between the presence or absence of adequate street illumination and the increasing number of traffic accidents, resulting in many cases in lamentable loss of life, is a subject which demands, and must receive, closer investigation than has hitherto been accorded to it. It is presumably not without significance in this connection that in London the accident hazard in such notoriously congested traffic areas as the Bank, Piccadilly Circus, and Trafalgar Square, where, however, the illumination is of a high order, is singularly less than in the more unsatisfactorily lighted thoroughfares in the suburbs.

A satisfactory system of street lighting should, then, enable pavements to be traversed in comfort and road crossings to be negotiated in safety. The ideal system should of course be such as not only to make it possible for daylight activities to be continued at night time with an equal degree of comfort and convenience, but to contribute to the amenities of the locality by beautifying the streets and buildings.

That such an order of illumination is not, even at the present time, beyond the sphere of practical politics, will be apparent from the illustrations shown in Fig. 97, which are reproduced from two photographs of a well-known London thoroughfare taken from the same view-point at mid-day and midnight respectively upon the same date.

Granting, then, the desirability of such lighting as has been indicated, how can it best be obtained ? What constitutes the most satisfactory system ? What type and size of lamps should be used ? In what type of lanterns or fittings should they be employed ? At what height above the roadway should the fittings be suspended ? At what distance apart should the standards be placed ? In what manner should they be arranged ? What order of intensity should be aimed at, to what extent should it be allowed to vary, and by what tests should the excellence or otherwise of the ultimate installation be judged ?

For the purpose of answering, at all events in part, these and other questions of equal or even greater import, and of affording engineers an opportunity of studying such problems on practical lines, several experimental street-lighting installations have been set up in America, one of the most notable being that at Nela Park, Cleveland, covering approximately 2,000 feet of a typical thoroughfare, and equipped with lighting units of varying types.

It is gratifying to record that the first installation of this type has now been established in this country at North Wembley, near London, where one of the foremost electrical companies has set up an excellent experimental equipment in the public highway adjoining its extensive and well-known research laboratories. This installation extends for a length of approximately half a mile, and comprises a varied and pre-eminently useful assortment of standards, lanterns, and general street-lighting equipment, which we understand is willingly shown in actual operation and demonstrated in detail to those interested. Being quite the newest installation of its kind, it naturally possesses features in advance of its predecessors, and some of these are of so interesting a nature that a brief description of them will undoubtedly be welcome.

The current supplying the lamps is controlled by a Tirrill regulator, which maintains a constant voltage regardless of the load, the cables being carefully proportioned, and arranged in such manner as to reduce the drop in volts along their length to a minimum.

Each of the lamp standards is of a different type or design, and each contains in its base a special panel upon which is mounted a series of terminals, switches, fuses, etc., so arranged and connected as to enable a voltmeter, amperemeter, or wattmeter, of either the indicating or the recording type, to be instantly placed in circuit with or across any desired lamp.

Each standard is also provided with an adjustable resistance, connected in series with the lamp which it carries, and by means of which the latter can be run at any desired terminal voltage or efficiency.

As an instance of the thoroughness of those responsible for the installation and the care which has been bestowed upon the perfection of its various details, it may be stated that an additional pair of leads of ample sectional area has been taken up each standard to the lamp-holder terminals, solely in order that such voltage measurements as are required may be made actually at the lamp terminals.

It is hardly possible to overestimate the importance of so essentially practical an aid to the work of the street-lighting engineer, and the vast amount of practical data obtained from the tests and experiments which its possession has enabled the company to carry out will be, it is thought, increasingly utilized by the street-lighting fraternity as the location and purpose of the installation become more widely known.

It is obviously impossible, within the space allotted to the subject in this volume, to deal exhaustively with all the various phases of street-lighting work. All that can be attempted in what follows is to give as briefly as may be such information as is likely to prove most helpful to both the student and the lighting engineer, and, more particularly, to emphasize those points which a practical experience extending over half a lifetime has shown to be of vital importance if a successful installation is to be obtained, or, having been obtained, is to be maintained at its highest efficiency.

Available Systems.—Ignoring for the moment the question of the utilization of any given supply of electrical energy, there are three different and distinct systems available for street-lighting purposes: the Constant-current Series System, the Constant-potential Series System, and the Constant-potential Multiple System, which are respectively shown diagrammatically by Figs. 98, 99, and 100.

The first two of these, although extensively adopted and successfully operated in America and elsewhere, are almost unknown in this country. As, however, they possess in common certain pronounced advantages, particularly in those cases where new plant is being installed specially for lighting purposes, or where separate lighting feeders can be taken from an existing supply station, as is now being done in certain suburban and outlying areas, it may be advisable to consider them in passing. The third system, namely, the Constant-potential Multiple System, is that most widely known and commonly used, as it is that upon which almost the whole of our public lighting is carried out.

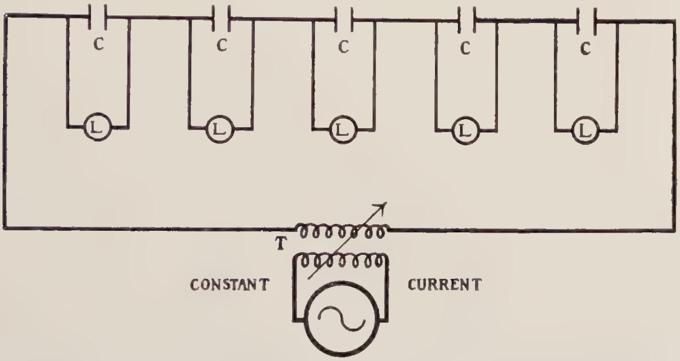


Fig. 98.—Constant-current Series System, using 'Disc'-type Flash-over Contacts. L=lamps; C=flash-over contacts.

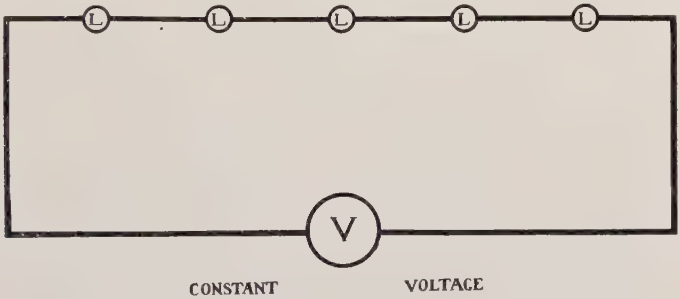


Fig. 99.—Constant-potential Series System. L=lamps.

(*a*) **Constant-current Series System.**—Although this system *can* be operated on a direct-current supply, it is, owing to difficulties in the construction, operation, and satisfactory regulation of the necessary D.C. generator, for all practical purposes considered only in connection with the employment of alternating current.

Its adoption involves the use of a constant-current transformer, as shown by T in Fig. 98, the current from which passes through the whole of the lamps L, each of which has connected across its terminals a disc-type flash-over contact C. Such contact-making devices are usually mounted immediately above the lampholder, and consist essentially, as will be seen from the illustration of a typical pattern shown by Fig. 101, of two substantial metal springs capable of making a sufficiently good contact to carry the full line current, and which are normally kept apart by the insertion between them of an easily renewable ' disc ' consisting of two metal portions, about three-eighths of an inch in diameter, separated by a piece of insulating paper of a special type, and of about the thickness of an ordinary cigarette-paper. In the event of the failure of any individual lamp, the full circuit voltage is impressed across the paper disc, and by immediately

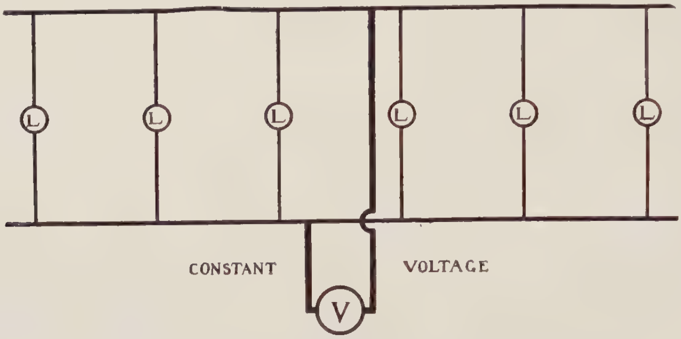


Fig. 100.—Constant-potential Multiple System. Circuit fed from electrical centre. L = lamps.

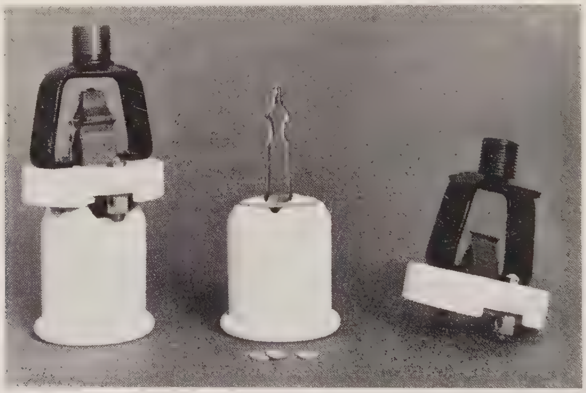


Fig. 101.—Disc-type Flash-over Contact. Three of the renewable 'discs' are shown in front of the lamp-holder portion in the centre of the illustration.

breaking down the insulation restores the circuit and allows the remaining lamps to continue burning.

The great advantage of the system lies in the fact that all series lamps are rated in amperes, as distinct from watts, and that, for any particular filament diameter, the value of the current to ensure any definite temperature and efficiency remains constant. The life of the lamps is in consequence usually more uniform, and their lumen output more constant, whilst the troubles due to variations in cable drop are naturally non-existent.

The design of lanterns, or fittings, for use on such a system requires careful consideration, particularly from the point of view of the insulation of the lampholder, which, if the number of lamps in series is large, as it usually is, operates at a voltage considerably above earth potential. It is for the purpose of eliminating this difficulty that the modified arrangement shown by Fig. 102 has been evolved.

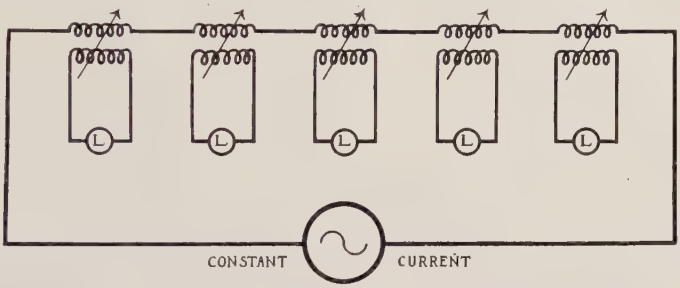


Fig. 102.—Constant-current Series System, using Small Series Transformer at each individual post. L = lamps.

In this method a small series transformer, of a constant-current ratio, is used at each individual post, thereby enabling 50-volt lamps to be used. If, as is best, and is usually arranged, this transformer is located in the base of the standard, the whole of the wiring passing up the inside of the post, together with the current-carrying portions of the lantern, or fitting, operates at a potential only 50 volts above that of earth. A further advantage lies in the fact that the employment of transformers of an appropriate ratio renders possible the use of a smaller main current at an appropriately increased pressure; this, in turn, enables a smaller and consequently less costly main cable to be used, with a saving in both capital outlay and cable losses.

It is also possible to vary the ratio of any individual transformer in such manner that, whilst the primary current remains fixed at the ampere rating at which the circuit as a whole is designed to operate, the current on the secondary side may be increased as desired. If, for instance, on a circuit using a considerable number of 6·6 ampere lamps, it is desired to provide increased illumination at the intersections of specially important streets by using larger lamps, the transformers at the points in question may be arranged to give a current on the secondary side of, say, 20 amperes.

For these reasons the use of the individual transformers is much to be preferred, and it is recommended that, wherever the use of the constant-current series system is contemplated, the method shown in Fig. 102 should, if possible, be adopted.

(*b*) **Constant-potential Series System.**—This system, which is applicable to either A.C. or D.C., is most frequently used in those cases where it is desired to convert existing arc-lamp circuits arranged to use four or five lamps in series on a 200 volts or 250 volts circuit. Many such circuits are now being utilized for lighting by high-wattage gas-filled lamps.

Such an arrangement, shown by Fig. 99, is considered by its advocates to possess certain of the advantages peculiar to the constant-current system previously dealt with, inasmuch as the voltage drop in any individual series of lamps may be eliminated.

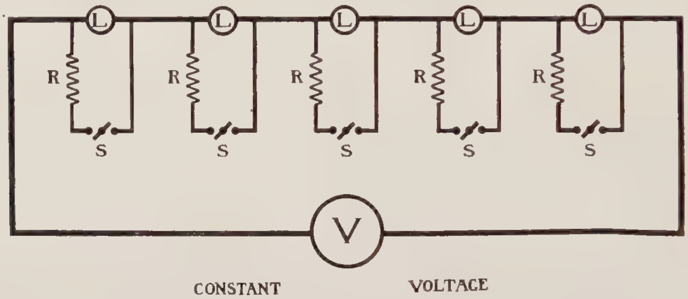


FIG. 103.—CONSTANT-POTENTIAL SERIES SYSTEM, USING AUTOMATIC SWITCHES AND SUBSTITUTIONAL RESISTANCES. L=lamps; R=resistances; S=automatic switches.

It must not be forgotten, however, that although this is true with regard to any particular series, the behaviour of the various groups of lamps will not differ in any sense from that of individual lamps burning in parallel—that is to say, the voltage of the respective series circuits, considered as units, will vary with their distance from the point of feed, and the light output of the lamps will differ accordingly. When sufficient care is exercised in the arrangement of the circuits, and particularly in the manner in which they are fed, this system, although by no means so satisfactory as the truly constant current system, may result in slightly better lighting being secured for a given input by reason of the fact that it enables advantage to be taken of the increased lumen output of the more efficient low-voltage lamps.

Its chief drawbacks are that the number of lamps which can be operated in any one series is limited by the voltage drop in the feeders and the available voltage of the supply system, and that, unless each lamp is provided with a suitable automatic switch and substitutional resistance, as shown by Fig. 103, the failure of a single lamp involves the complete shut-down of the whole of the particular circuit affected.

Where the lamps are burning on an alternating-current circuit, choking coils, or, as they are sometimes called, safety coils, can be used with advantage as an alternative to the use of automatic switches and substitutional resistances, in the manner shown diagrammatically by Fig. 104.

In this arrangement a choking coil C, wound on a laminated iron core, is connected across each lamp as shown. During the time the lamp is burning only the magnetizing current passes through the coil, the loss in the winding of which need not exceed from 20 to 30 watts, which is very little more than the loss in the shunt coils of an automatic switch. On the failure of a lamp the full line current passes through the choker winding, which is so proportioned that under these conditions the voltage drop across the coil is equivalent to the voltage of the lamp which has failed, so that the circuit as a whole remains unaffected.

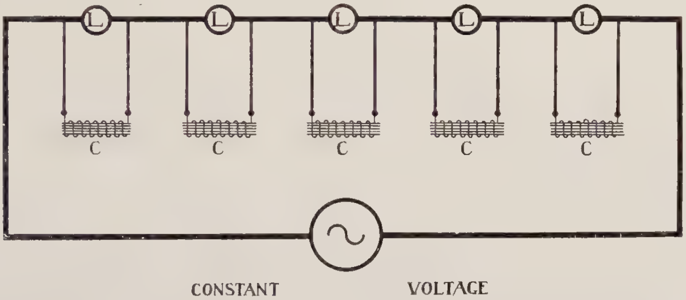


Fig. 104.—Constant-potential Series System, using Iron-cored Choking Coils. L = lamps; C = choking coils.

Such choking coils are not only comparatively inexpensive, but cost practically nothing to maintain owing to the fact that they are wound with thick wire and that the arrangement is entirely static, *i.e.* that there are no moving parts or contacts to cause trouble.

(*c*) **Constant-potential Multiple System.**—This system, shown diagrammatically by Fig. 100, is so well known as to call for very little in the way of either comment or explanation, as it is the one adopted in respect of fully ninety per cent. of existing street-lighting installations.

The greatest difficulty which is likely to be encountered in this system, and the one to which, unfortunately, all too little attention has been paid in the past, is in the arranging of the circuits in such a manner as to reduce the voltage drop in the cables to the absolute minimum. It is by no means an uncommon experience to find circuits of from twelve to twenty lamps, or more, fed from one end of the line, with the result that the last lamp is operating at a voltage so considerably below that for which it is rated that its light output quite conceivably may be no more than sixty to seventy per cent. of its full value.

Another difficulty in such cases is that, as the pressure falls along the line, each individual lamp is operating at a voltage differing from that of both the one before it and the one beyond it, with the result that, instead of the lumen output of the various lamps along the thoroughfare being reasonably constant, the intensity of the illumination and the appearance of the lamps tail off from the feed-in end of the circuit to its most remote point.

As this question will be discussed more fully when considering the matter of lamps, it is sufficient at this stage to state that, when the total number of lamps is few, the circuit should, whenever possible—and usually it is possible with a little trouble—be fed from the middle or electrical centre, as shown in Fig. 100. Where the number of lamps is large, and really satisfactory lighting is desired, it is essential that the circuit be fed from a number of points, as indicated in Fig. 105, the points at which the feeders are connected being so arranged as to equalize the pressure as far as possible.

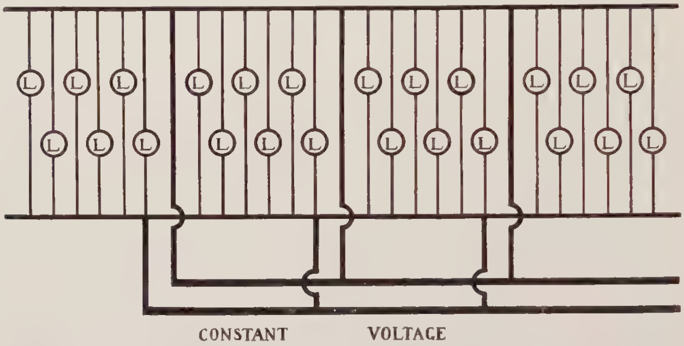


Fig. 105.—Constant-potential Multiple System. Circuit fed from a number of points so arranged as to give approximately equal pressure. L=lamps.

Available Methods.—The system upon which the lighting is to be operated having been determined, there remains to be considered the method to be employed.

The relation of the manner in which the actual lighting units are to be suspended, or supported, and the securing of a satisfactory and withal pleasing arrangement of the particular equipment utilized for this purpose, are matters requiring, and well repaying, careful thought. A wise choice, at which it is by no means easy to arrive, involves the weighing in the balance of quite a number of apparently conflicting considerations.

The first point to be settled is whether the lanterns are to be carried by overhead suspensions (see Fig. 106), or supported by brackets or standards (see Figs. 108 and 110).

Overhead Suspensions.—The question of the fixing to the face of the buildings, on each side of the road, of the rosettes for the attachment of the overhead span wires, calls for consideration.

If, as is frequently the case, the city council or local authority has powers permitting the making of such attachments, the matter is comparatively simple; but if otherwise, the obtaining of the necessary wayleaves, which must be secured before the work can be commenced often proves a protracted and costly business.

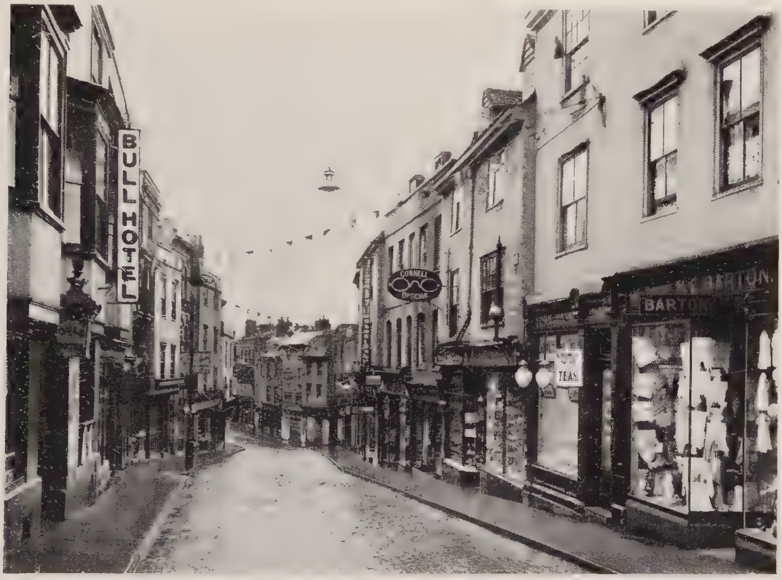


FIG. 106.—OVERHEAD SUSPENSION. SPAN WIRES ATTACHED TO BUILDINGS ON EACH SIDE OF ROAD.

Special provision will have to be made for those points at which side streets lead off from the main thoroughfares, and for junctions of two, three, four, or more streets where such occur. The single-span suspension wire is, in these cases, replaced by a three, four, or five wire suspension; where the points of attachment of these various wires are at unequal distances from the position in which the lantern is required, care must be taken that the strain on each is approximately equal. If any positions are particularly exposed it may prove necessary to provide light stay wires, in addition to the actual suspension wires, to prevent the lanterns from swinging in the wind to an undue extent.

If buildings of sufficient height are not available for the support of the overhead suspension wires, their place can of course be taken, either wholly or in part, by steel poles fixed at the edge of the curbstone, as shown in Fig. 107.

Brackets.—If the use of brackets is decided upon, their location and arrangement are frequently matters of considerable moment.

Brackets may, if powers are possessed or permission is obtained, be attached to suitable buildings, where such exist, in the manner shown in Fig. 108, or to trolley-wire standards (see Fig. 109), where these are available and are the property of the lighting authority. They are, however, rarely fixed to buildings, except in the few special cases in which other forms of support are unsuitable, as unless the streets are unusually narrow, or the brackets project an unusual distance, the lanterns are too near the side walls, and too far removed from the centre of the road, to enable the most satisfactory distribution to be obtained.

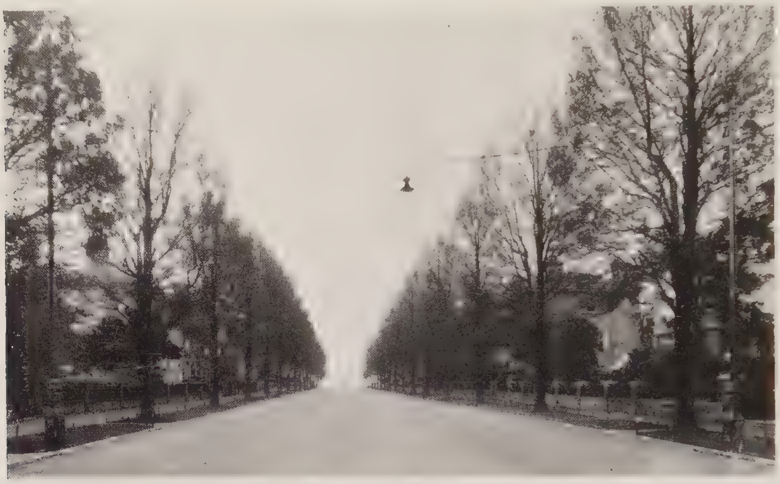


Fig. 107.—Overhead Suspension. Span wires attached to steel poles at edge of curbstone.

Their use on tramway trolley-wire standards is a much more satisfactory proposition, as the latter are usually not only of ample height, but are arranged at the outside edge of the footpath. Under these conditions both the roadway and the footpath can be much more evenly and satisfactorily illuminated, and there are, as a matter of fact, in existence quite a number of efficient installations carried out in this way.

Standards.—The use of standards, although by far the most generally accepted and satisfactory method of supporting street-lighting fittings, is not always to be advocated without qualification. Many streets are, for instance, already equipped with tramway poles, and it might, in such cases, be extremely undesirable to add to their obstruction by the introduction of a further series of lofty standards for the accommodation of improved lighting devices. Moreover, it frequently happens in such cases that positions at which columns must be erected to furnish light at street intersections are already occupied by tramway poles.

Where their use is permissible, the two principal points to be determined are the type to be employed—that is to say, the material of which they are to be constructed—and the manner in which they are to be arranged.

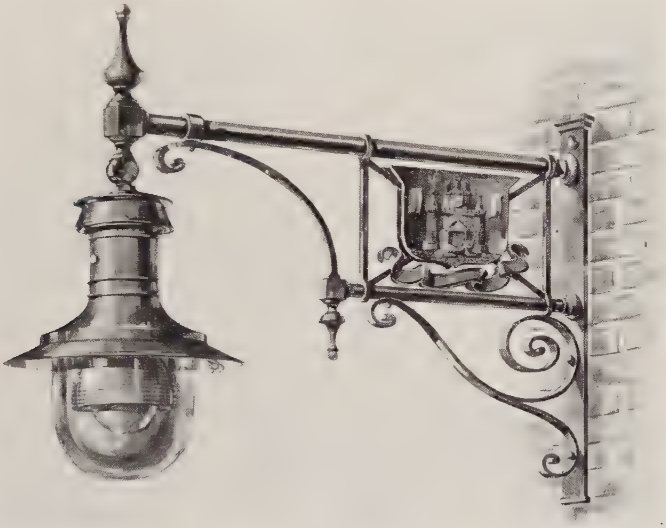


Fig. 108.—Bracket attached to Building.

Cast-iron standards, typical examples of which are illustrated in Fig. 110, have been almost universally used in the past, and are, on account of their lower cost, still much in favour.

The growth during recent years of serious accidents due to the breaking and falling of cast-iron poles struck by heavily laden or rapidly moving vehicles, has, however, led to the increased use of tubular steel standards, which, although they may be bent, cannot, obviously, be fractured by impact, and are therefore considerably safer in service. Such tubular columns are usually tapered, and are frequently provided with an ornamental cast-iron base of appropriate size and shape, such as is illustrated in Fig. 111, in which case the steel tube should be arranged to pass *through* the base and extend for a suitable distance, dependent upon the height, into the ground.

Reinforced-concrete standards are now being used in increasing numbers, particularly in such locations as parks, gardens, and the grounds of exhibitions and public institutions, where the height required is usually not very great. Fig. 112 illustrates the concrete standards used for carrying the ornamental lighting units installed throughout the grounds of the British Empire Exhibition at Wembley.

Upon the arrangement and location of the standards depend, in large measure, both the appearance of the streets by day and the nature and utility of the illumination by night, and it should not in this connection be forgotten that the duration of the periods during which the equipment is visible by daylight greatly exceeds those during which it may be considered to be fulfilling the function for which it is provided.

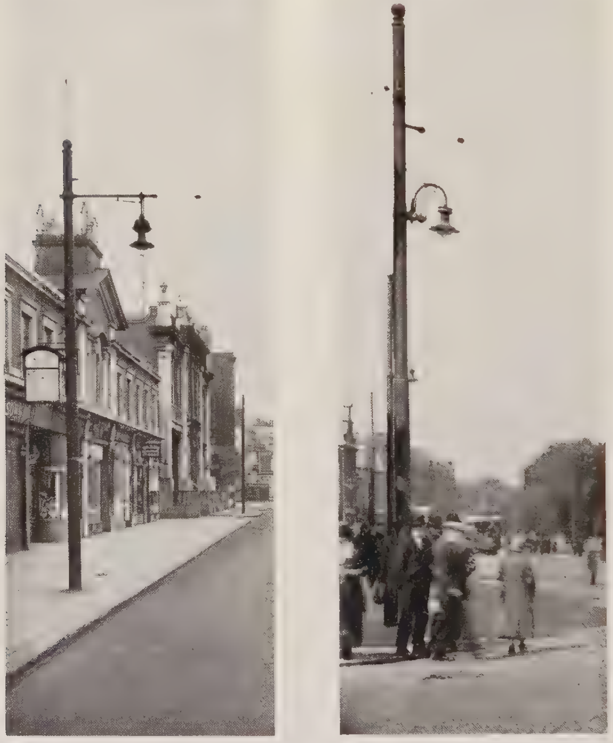


FIG. 109.—BRACKETS ATTACHED TO TROLLEY-WIRE STANDARDS.

The three arrangements most frequently adopted are: (*a*) Central Standards, (*b*) Symmetrical Standards, and (*c*) Staggered Standards, as shown in plan by Fig. 113.

Central Standards.—The use of central standards, *i.e.* standards placed on islands along the centre of the road, is usually limited to wide thoroughfares illuminated by powerful light sources suspended at a considerable height. Classical examples are Oxford Street, London (Fig. 114), and Princes Street, Edinburgh, in both of which, however,

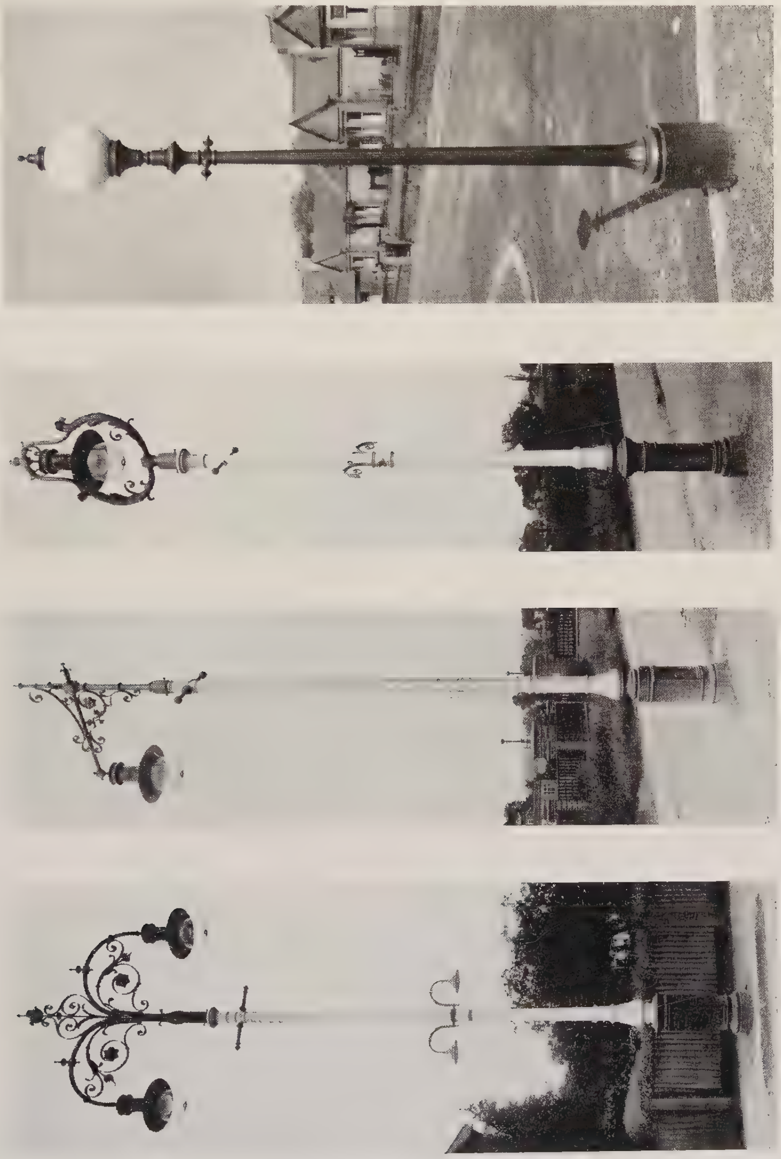


Fig. 110.—Typical Examples of Cast-iron Standards.

although the æsthetic value of the equipment leaves little to be desired, the actual minimum illumination is, unhappily, of a low order judged by present-day standards.

The main drawback to the adoption of this method is that modern road-construction does not readily lend itself to either the laying or the maintaining of the necessary mains, which must either run along the middle of the road or, if laid under the pavement, must cross it at frequent intervals. Another objection, urged by some, is that the islands constitute an obstruction to, and impede, the flow of traffic. The first of these difficulties can usually be overcome by the use of conduits of ample size, and, if the cables are run under the pavement, the provision of a sufficient number of conveniently placed underground junction chambers. The second amounts merely to an expression of opinion, and is offset by the view held and expressed by many authorities, and supported by experience, that the regulation of traffic is helped rather than hindered by the presence of the islands and

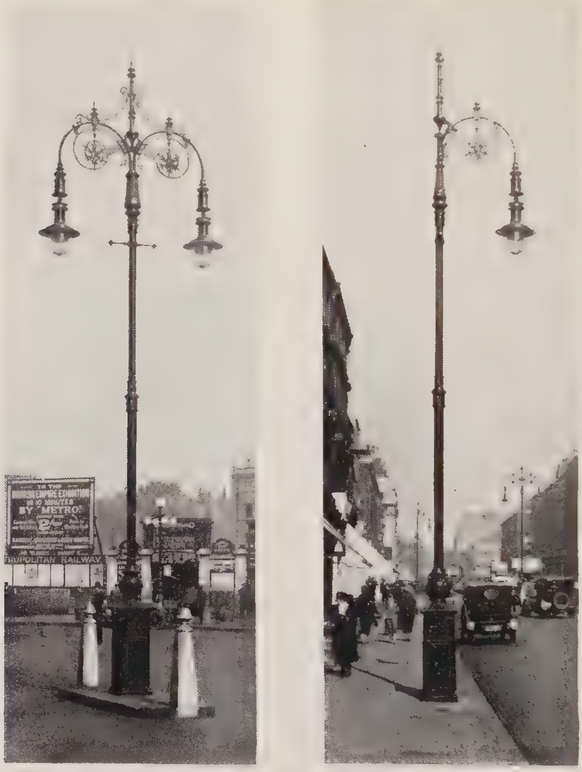


Fig. 111.—Typical Examples of Tubular Steel Standards.

posts. That the former are appreciated and extensively utilized by pedestrians desiring to cross from one side of the road to the other is a matter of common knowledge.

Symmetrical Standards.—Symmetrical standards—*i.e.* standards arranged opposite to one another along both sides of the road—although not as yet adopted to any pronounced extent in this country, are largely used in America, and are steadily increasing in popularity.

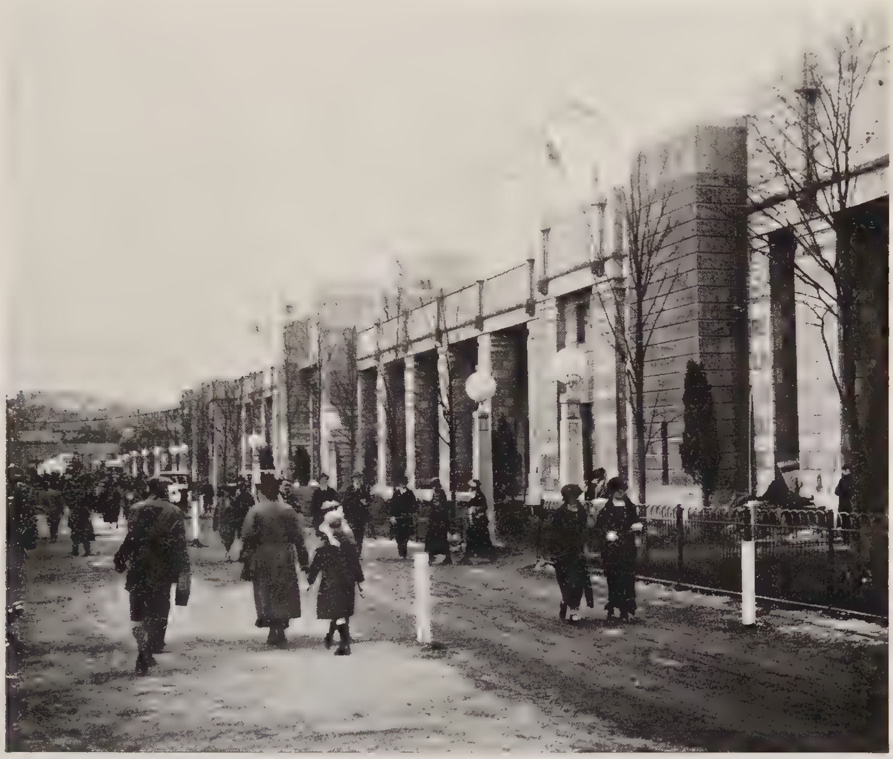


Fig. 112.—Reinforced-Concrete Standards carrying Ornamental Lighting Units, as installed throughout the Grounds of the British Empire Exhibition at Wembley.

Lighting units arranged in this way unquestionably present a more pleasing appearance when in operation, whilst the greater symmetry adds materially to the ‘ daytime ’ effect. If, therefore, the decorative value of the equipment is of primary importance, the method has much to recommend it. It is particularly applicable to the lighting of thoroughfares of the boulevard type, or those passing through or adjacent to public spaces, parks, or gardens, and will, it is thought, be increasingly used in the future for the lighting of better-class residential areas.

Its only drawback, if such it can be called, is of course the greater number of standards, lanterns, and lamps required for the illumination of any given length of street.

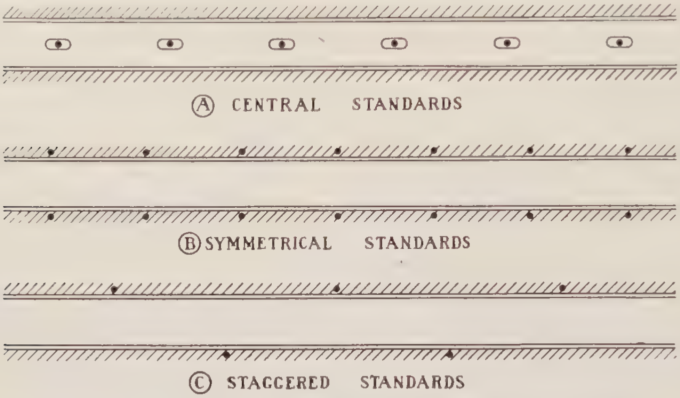


Fig. 113.—Alternative Methods of arranging Standards.

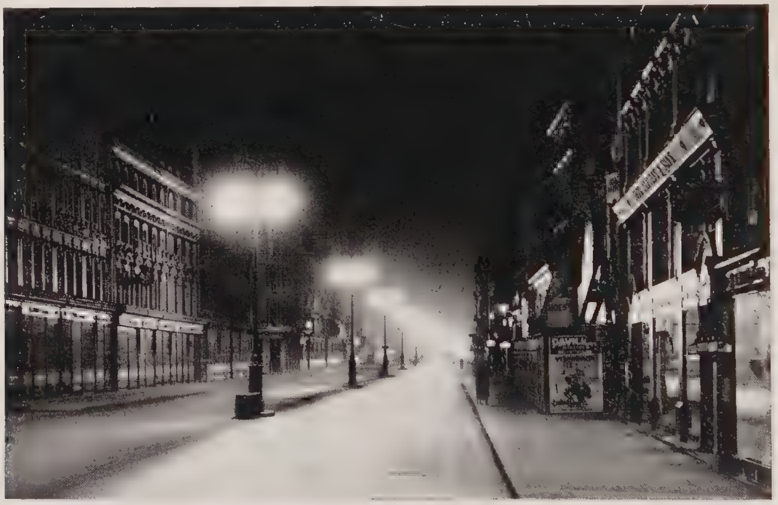


Fig. 114.—Central Standards in Oxford Street, London.

Staggered Standards.—Staggered standards, *i.e.* standards arranged along both sides of the road in such manner that each is located midway between two standards on the opposite side, are very extensively used; in fact, by far the greater proportion of the public lighting units in use throughout the country are arranged in this way.

Considered solely from the strictly utilitarian point of view, this arrangement is the one which, in streets of ordinary width, enables the most satisfactory illumination for seeing purposes to be provided with the minimum number of standards, and it is undoubtedly this consideration which has led to its widespread adoption. Such an arrangement is most satisfactory in streets of considerable length, but possesses the drawback that in short streets, or those in which the number of side turnings or cross streets is at all pronounced, it is most difficult to provide adequate illumination at the points of intersection, as should always be done as far as possible, without seriously impairing either the symmetry of the arrangement or the length of the spans.

Whatever may be the manner in which the standards are arranged, the question of their position in relation to the edge of the roadway is of special importance and should not be overlooked. In the case of posts fixed on central islands, the latter should be of ample width; whilst in the case of standards along the edge of the footpath, the extent to which they are set in from the outer edge of the curbstone should be sufficient for safety. The increased camber adopted in modern road-construction, and the greater overhang and height of vehicles of later types, are matters of moment in this connection. As instancing the need for care in this direction, reference may be made to the recent introduction of motor buses provided with a covered-in upper deck. It is obvious that if a bus of this description is compelled for any reason to travel close to, or stop at, the outer edge of a well-cambered road, the highest point of the side of the vehicle adjacent to the pavement may project inwards from the curb to an extent sufficient to constitute a danger unless really adequate clearance is provided.

Switching.—Where the public lighting is supplied from feeders which are used exclusively for this purpose, the switching 'on' and 'off' of the various circuits is a comparatively simple operation which can be carried out either from the supply station or from suitable section boxes fixed at convenient points along the route.

Where this is not possible, owing, for instance, to the mains being also utilized for the supplying of current to private consumers, either a separate switching-main must be run (Fig. 115), or other arrangements must be made. Lamps carried by overhead suspensions, or on brackets attached to buildings, can be controlled either singly or in groups by single-pole, or preferably double-pole, switches mounted in cast-iron water-tight cases, provided with a suitable actuating lever, fixed to the face of the buildings, and operated by a short pole carried by the 'lamplighter.'

Lamps supported by brackets on tramway poles, or by tall standards erected for the purpose, can be similarly controlled by switches attached to the trolley poles or standards, or accommodated in the base of the latter (which must of course be provided with a door), as may be most convenient.

Where the standards are not too high, a third method is available, namely, the provision at each point of a suitable switch incorporated in, or attached above or beneath, the spigot cap by means of which the bracket or harp carrying the lantern is joined to the actual column.

In each of these cases the hand-operated switches previously referred to may with advantage be replaced by automatic time switches in which the operation of switching 'on' or 'off' is performed by a simple mechanism actuated and controlled by a suitable clockwork movement. Such switches, set to operate in either direction at any predetermined time, only require winding at infrequent intervals, have proved exceedingly satisfactory and reliable in service, and possess the by no means inconsiderable advantage, in these days of expensive labour, of materially reducing operating costs. They can also be obtained so arranged as to control a double circuit, both circuits being switched 'on' together and 'off' separately. This method is particularly useful where half- and whole-night lighting is required.

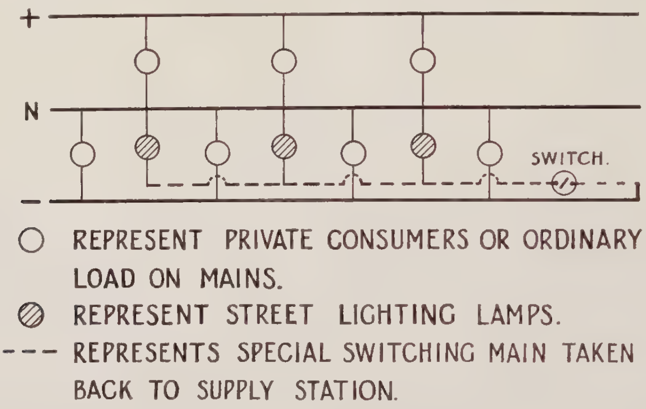

+
N
−
SWITCH.
○ REPRESENT PRIVATE CONSUMERS OR ORDINARY LOAD ON MAINS.
▨ REPRESENT STREET LIGHTING LAMPS.
--- REPRESENTS SPECIAL SWITCHING MAIN TAKEN BACK TO SUPPLY STATION.

FIG. 115.—TYPICAL ARRANGEMENT OF SEPARATE SWITCHING MAIN.

A selection of typical switches for hand operation is illustrated in Fig. 116, whilst Fig. 117 shows a representative range of time switches.

When determining the capacity of the switches to be used (and this of course applies equally to fuses), care should be taken, especially in the case of circuits on which large numbers of lamps are burning in parallel, to allow for the overshoot on gas-filled lamps, which may amount to from twelve to fifteen times the normal running current.

Cleaning and Re-lamping.—The manner in which such cleaning of lanterns and renewal of lamps as may be necessary is to be carried out demands attention. Apart from the employment of hand ladders, the alternatives are the use of either hand or motor tower-waggons, or —and this is much to be preferred—in the case of overhead suspensions the provision of traversing, lowering, and contactor gear for each lantern, controlled by winches actuated by removable handles and fixed to the buildings at a height sufficient to render unlikely their being tampered with by unauthorized individuals.

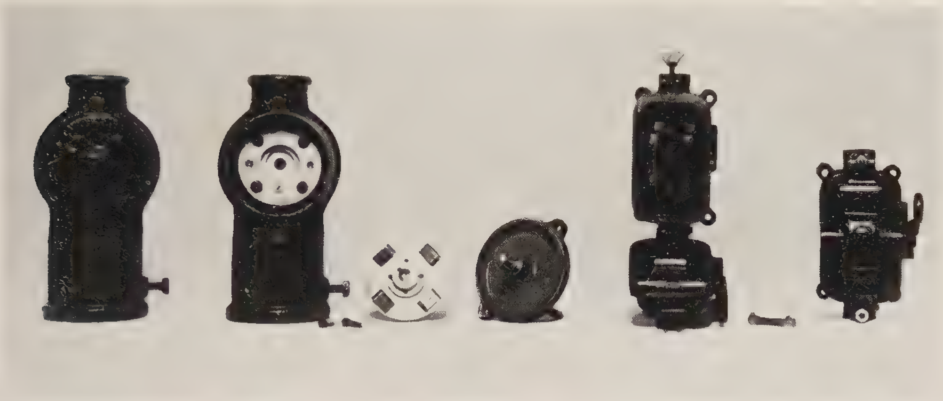


Fig. 116.—Group of Typical Switches for Hand Operation.

In the case of lamps on brackets or standards the contactor gear is fixed above the lantern, and the lowering is carried out by winches fixed on the wall, or upon or within the base of the standard, as the case may be.

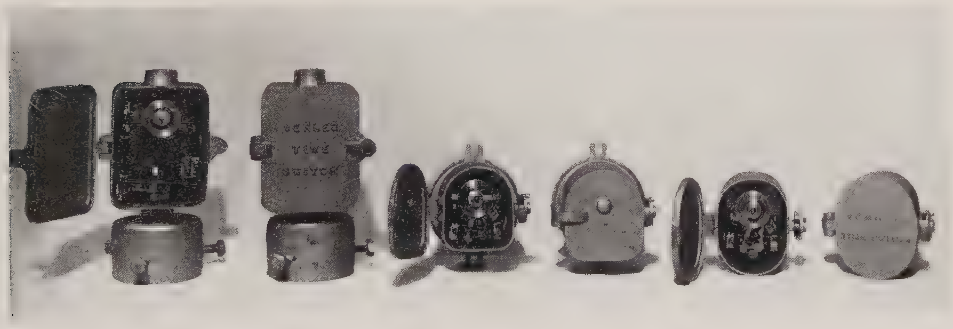


Fig. 117.—Representative Range of Automatic Time Switches.

Illumination Required.—The municipal engineer or lighting superintendent contemplating the designing of an installation of street lighting, or the remodelling of an existing system in such manner as to bring it into line with present-day requirements, will seek in vain for anything in the nature of a standard street-lighting specification to which he can work, or an official pronouncement as to the degree of illumination necessary or desirable for streets of any particular class.

Much has been written, and still more has been spoken, on the subject. Conferences and committees formed in this and other countries have deliberated at length, but have so far failed to reach agreement. At the International Convention held at Geneva in 1924 the matter was again considered, and after discussion was referred back to the national committees to be brought up at the next international meeting.

The matter is now being further considered by an influential and representative committee recently set up by the British Engineering Standards Association, and it is hoped that, as a result of its work, the long-awaited standard specification may eventually materialize.

The Joint Committee of 1911 suggested as suitable for various classes of streets minimum values of horizontal illumination, measured on a plane 3 feet 3⅜ inches above ground-level, ranging in five stages from 0·1 foot-candle for principal streets to 0·01 foot-candle for those of lesser importance. These values are so hopelessly inadequate under present-day conditions that they are now only of interest as indicating the ideas then prevailing, and the timidity with which the question was approached.

The latest and certainly the most useful contribution to the subject which has yet appeared is contained in the recommendations made by the Street and Highway Lighting Committee in June 1925, in its report to the National Electric Light Association at San Francisco, and which we reproduce from the Official Report.

TABLE XVIII

RECOMMENDED STREET-LIGHTING PRACTICE FOR CITIES OF 100,000 POPULATION OR LARGER

Street Class	Lumens per Post	Mounting, Ht.—Ft.	Lamp Spacing, Feet	Minimum Lumens per Ft. of Street	Desirable Lumens per Ft. of Street	Arrangement of Lamps
Principal Business	15000–50000	18–25	100–150	400	400–1000	Opposite
Secondary Business	10000–25000	15–18	80–125	200	200–500	Opposite
Principal Thoroughfares	10000–15000	15–20	100–150	70	70–200	Opposite or Staggered
Boulevards and Parks	4000–10000	15–20	100–150	30	30–100	Opposite or One Side
Secondary Thoroughfares	4000–10000	15–20	100–150	30	30–70	Staggered
Wholesale Mfg. Dis., Residential	2500–4000	13–20	125–200	15	15–30	Staggered
Alleys, Business Sec.	2500–4000	16–20	125–200	15	15–30	One Side
Outlying Streets and Alleys	1000–2500	16–20	200–300	3	3–8	One Side

TABLE XVIII—*continued*

30,000 TO 100,000 POPULATION						
Principal Business . .	10000–30000	15–20	80–125	300	300–500	Opposite
Secondary Business . .	10000–15000	15–18	80–125	200	200–300	Opposite
Principal Thoroughfares .	6000–15000	15–20	100–150	40	40–150	Staggered
Boulevards and Parks . .	4000–10000	15–20	100–150	30	30–100	Opposite or One Side
Secondary Thoroughfares .	4000–10000	15–20	100–150	30	30–70	Staggered
Residential	2500–4000	13–20	125–200	15	15–30	Staggered
Outlying Streets and Alleys .	1000–2500	16–20	200–300	3	3–8	One side
5,000 TO 30,000 POPULATION						
Business	6000–15000	14–18	80–125	120	120–300	Opposite
Primary Thoroughfares .	4000–10000	15–20	100–200	30	30–100	Staggered
Secondary Thoroughfares .	4000–6000	15–20	100–200	20	20–60	Staggered
Residential	2500–4000	13–20	150–250	10	10–20	Staggered or One Side
Outlying Streets and Alleys .	1000–2500	16–20	200–300	3	3–8	One Side
5,000 POPULATION OR LESS						
Business	4000–10000	13–16	80–110	80	80–200	Opposite
Thoroughfares	2500–6000	15–20	100–200	20	20–60	Staggered or One Side
Residential	2500	13–20	150–300	8	8–15	Staggered or One Side
Outlying Streets and Alleys .	1000–2500	16–20	200–300	3	3–8	One Side
HIGHWAYS						
Light Pavement	2500–4000	25–35	300–400	6	6–12	One Side
Dark Pavement and Dirt Roads	2500–4000	25–35	200–300	8	8–20	One Side

These recommendations—for so far they do not, unfortunately, amount to anything more—reveal so admirable a grasp of modern requirements, and are of so epoch-making a nature, that it is both interesting and instructive to examine them closely and, as far as possible, to compare them with what has been, and is being, done here. Points of interest are that the cities are graded according to their population, that the streets are classified in the order of their importance, and that the highest illumination is specifically stated to apply to the principal business streets.

For cities the population of which is 100,000 or more, which in Great Britain would include such cities as London, Manchester, Liverpool, Birmingham, and Glasgow, a value of from 15,000 to 50,000 lumens per post, or 400 to 1,000 lumens per foot of street, is specified.

The mounting height is given as from 18 to 25 feet, the span as from 100 to 150 feet, and the standards are stated to be placed along both sides of the road opposite to one another. No information is given as to the width of the roadway. Some idea of such lighting at its best is conveyed by Fig. 118, which portrays the appearance by night of a typical American thoroughfare.

Comparing the foregoing with British practice, two 1,500-watt lamps per post would give 45,000 lumens per post. Assuming the greatest mounting height, *i.e.* 25 feet, the longest span, *i.e.* 150 feet, and an actual road width of 80 feet—equivalent to such London thoroughfares as the Thames Embankment, Whitehall, and Kingsway—standards arranged as specified and each provided with two 1,500-watt lamps in efficient lanterns would give, with new lamps and clean glassware, a minimum mid-span illumination, on a horizontal plane 3 feet above ground-level, of approximately 2·0 foot-candles.

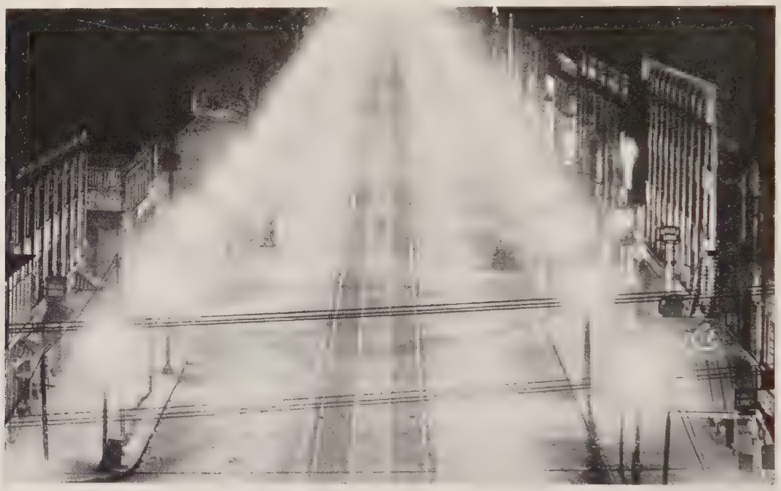
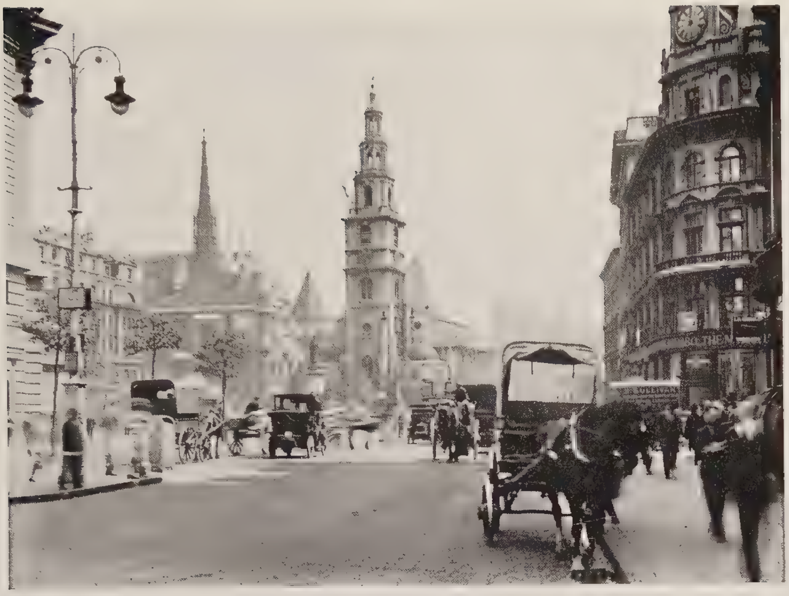
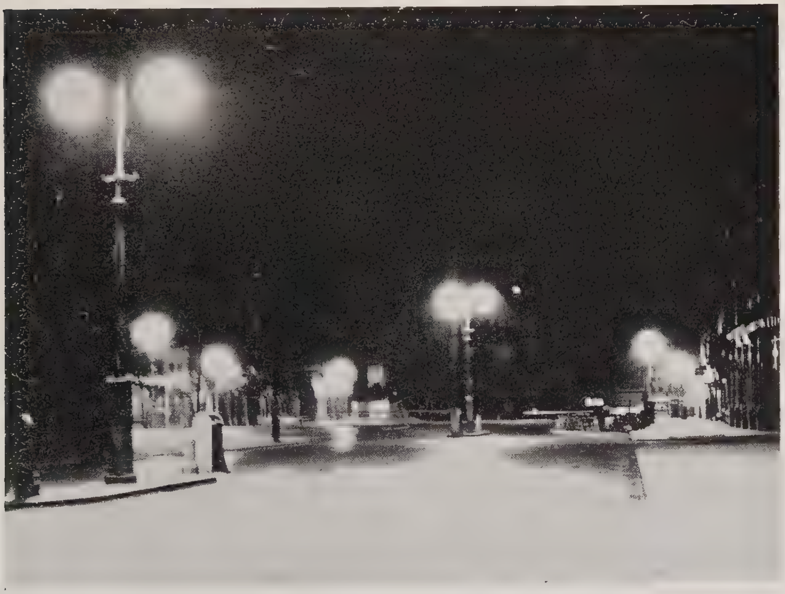


Fig. 118.—Illumination of typical American Thoroughfare.

The electrically illuminated portions of the Charing Cross area are admittedly among the best, if not actually *the* best, lighted thoroughfares in England, and in all probability in Europe. Throughout the whole of this extensive area the lanterns used are suspended at a height of 25 feet from road-level to filament. The spans range from 100 to 150 feet, and two lanterns are provided per post. In such streets as the Strand (Fig. 119), Whitehall, Cockspur Street, Northumberland Avenue, and Charing Cross Road, two 1,500-watt lamps are used per post. In less important streets, such as St. Martin's Lane, King William Street, Villiers Street, Whitcomb Street, and Long Acre, two 1,000-watt lamps are used per post.



(*Reproduction of photograph taken by daylight.*)



(*Reproduction of photograph taken after nightfall.*

FIG. 119.—THE STRAND (LONDON) BY DAY AND BY NIGHT.

The calculated mid-span intensities on a horizontal plane 3 feet above ground-level, and assuming new lamps and clean glassware, are for the 1,500-watt lamps from 2·7 to 0·925 foot-candles according as the span varies from 100 to 150 feet, the average value being 1·8 foot-candles. Corresponding values for the 1,000-watt lamps are from 1·8 to 0·62 foot-candles respectively, the average being 1·2 foot-candles.

It is therefore apparent that the value of illumination prescribed in the American report as a perfectly normal value for the principal business streets of perfectly normal towns is approximately 11 per cent. higher than that provided in the best-lighted thoroughfares in England, and is no less than the astonishing figure of 1,900 per cent. greater than the upper limit of 0·1 foot-candle suggested by the Joint Committee of 1911.

In these circumstances no apology is made for suggesting, as more correctly representing present-day practice and as more in keeping with the trend of modern progress, the modest values given in the following table (Table XIX). The intensities specified therein assume, in each case, the use of new lamps and clean glassware, and are those which it is suggested should be obtained at the mid-span position on a horizontal plane 3 feet above ground-level.

TABLE XIX

Class of Street	Minimum Horizontal Illumination in Foot-Candles at Mid-Span	Range of Horizontal Illumination in Foot-Candles at Mid-Span	
		Lower	Upper
A	0·5	0·5	2.0
B	0·25	0·25	0·5
C	0·1	0·1	0·25
D	0·05	0·05	0·1
E	0·025	0·025	0·05

It will be understood that the securing of any given minimum horizontal illumination at the mid-span position depends upon (*a*) the height of the light source above the highway, (*b*) the distance between adjacent sources, *i.e.* the span or spacing, and (*c*) the polar curve of the particular lighting unit which is being installed.

Tables XX and XXI give for various heights and spacings the angle in degrees and minutes between the vertical and a light ray reaching the plane of reference at the mid-span position, and the candle-power required at that angle from *each* light source to produce a horizontal illumination of 0·10 foot-candle at a point midway between columns. In Table XX the plane of reference is that usually adopted, namely, 3 feet above ground-level, whilst Table XXI is calculated for actual ground-level.

TABLE XX

CANDLE-POWER I_ϕ REQUIRED FROM EACH LIGHT SOURCE AT ANGLE ϕ WITH THE VERTICAL TO PRODUCE A MINIMUM HORIZONTAL ILLUMINATION OF 0·1 FOOT-CANDLE ON A HORIZONTAL PLANE THREE FEET ABOVE GROUND-LEVEL MIDWAY BETWEEN LIGHT SOURCES

HEIGHT	10		12		14		16		18		20		25		30		35	
SPACING	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ
50	74°21′	124·8	70°12′	104·2	66°15′	92·6	62°31′	86·0	59° 2′	82·6	55°47′	81·3	48°39′	83·9	42°47′	92·2	38° 0′	104·6
54	75°28′	155·0	71°34′	128·1	67°50′	112·6	64°17′	103·4	60°57′	98·3	57°48′	95·5	50°49′	96·0	45° 0′	103·2	40° 9′	114·7
56	75°58′	171·8	72°11′	141·3	68°33′	123·7	65° 6′	113·2	61°49′	106·8	58°44′	103·4	51°51′	102·7	46° 3′	109·0	41°11′	120·1
60	76°52′	208·9	73°18′	170·1	69°52′	148·4	66°34′	134·4	63°26′	125·8	60°28′	120·7	53°45′	117·1	48° 1′	121·8	43° 9′	131·9
64	77°40′	251·4	74°17′	203·8	71° 2′	176·2	67°53′	158·3	64°53′	147·1	62° 1′	139·9	55°29′	133·0	49°50′	135·8	45° 0′	144·8
66	78° 1′	273·7	74°45′	225·6	71°34′	191·4	68°30′	171·6	65°33′	158·7	62°45′	150·5	56°19′	141·9	50°43′	143·6	45°53′	151·8
70	78°41′	324·3	75°35′	262·4	72°33′	224·4	69°37′	200·0	66°48′	184·0	64° 6′	173·4	57°51′	160·6	52°21′	156·3	47°34′	166·7
75	79°26′	397·3	76°30′	318·4	73°39′	270·6	70°53′	240·6	68°12′	219·7	65°36′	205·0	59°36′	186·8	54°14′	182·6	49°31′	187·1
80	80° 4′	477·3	77°19′	382·6	74°37′	324·1	72° 0′	286·4	69°26′	259·5	66°59′	241·7	61°11′	216·1	55°58′	207·9	51°21′	210·2
85	80°39′	571·3	78° 3′	456·2	75°29′	384·1	73° 0′	338·1	70°33′	304·7	68°12′	282·1	62°38′	249·1	57°35′	236·6	53° 1′	235·2
90	81° 9′	672·8	78°41′	536·0	76°16′	452·2	73°53′	395·0	71°34′	355·8	69°18′	327·2	63°57′	285·7	59° 2′	267·6	54°35′	263·1
95	81°37′	790·6	79°16′	627·0	76°58′	527·5	74°42′	459·9	72°28′	411·5	70°21′	380·0	65° 9′	326·1	60°23′	302·0	56° 2′	293·6
100	82° 2′	920·3	79°48′	729·3	77°38′	615·9	75°26′	531·1	73°18′	474·1	71°13′	432·9	66°15′	370·4	61°38′	339·9	57°23′	326·9
110	82°45′	1219·0	80°42′	959·6	78°41′	800·7	76°42′	694·1	74°45′	618·2	72°49′	560·4	68°12′	472·5	63°51′	425·8	59°48′	402·3
120	83°21′	1577·6	81°28′	1239·6	79°37′	1033·4	77°46′	888·2	75°58′	789·0	74°11′	713·6	69°52′	593·4	65°46′	527·1	61°56′	491·6
130	83°51′	1992·6	82° 7′	1569·6	80°23′	1297·7	78°41′	1118·3	77° 0′	988·3	75°21′	893·2	71°18′	734·3	67°26′	645·0	63°47′	593·9
140	84°17′	2479·0	82°40′	1947·5	81° 4′	1615·7	79°29′	1389·7	77°54′	1221·5	76°21′	1099·5	72°33′	897·4	68°54′	781·3	65°26′	712·5
150	84°40′	3050·8	83° 9′	2387·0	81°39′	1975·5	80°10′	1696·4	78°41′	1488·8	77°14′	1339·1	73°39′	1084·8	70°12′	937·8	66°54′	847·8
160	85° 0′	3700·7	83°35′	2901·5	82°10′	2389·7	80°46′	2045·5	79°23′	1824·0	78° 0′	1607·8	74°37′	1296·4	71°21′	1114·6	68°12′	999·7
180	85°33′	5245·2	84°17′	4097·9	83° 2′	3390·5	81°47′	2894·7	80°32′	2528·5	79°19′	2268·1	76°16′	1808·7	73°18′	1536·1	70°26′	1363·1
200	86° 0′	7217·9	84°51′	5599·6	83°43′	4614·9	82°36′	3955·1	81°28′	3443·4	80°23′	3099·5	77°36′	2444·0	74°53′	2055·2	72°15′	1807·0
220	86°22′	9627·0	85°20′	7520·4	84°17′	6121·5	83°16′	5245·5	82°14′	4558·4	81°13′	4058·5	78°41′	3202·6	76°13′	2695·2	73°47′	2350·7
240	86°40′	12463·0	85°43′	9720·6	84°46′	7972·6	83°49′	6762·2	82°52′	5875·0	81°56′	5229·5	79°37′	4133·4	77°19′	3443·7	75° 4′	2991·9
270	87° 2′	17673·0	86°11′	13732·0	85°21′	11355·0	84°30′	9597·1	83°40′	8380·6	82°49′	7390·5	80°45′	5826·7	78°41′	4823·8	76°40′	4174·5
300	87°20′	24328·0	86°34′	18856·0	85°48′	15401·0	85° 3′	13153·0	84°17′	11383·0	83°32′	10115·0	81°39′	7902·0	79°48′	6563·8	77°57′	5627·2

Height is in feet from ground-level to centre of light source. Spacing is distance in feet between light sources. ϕ is angle to nearest minute that light ray makes with vertical.

TABLE XXI

CANDLE-POWER I_ϕ REQUIRED FROM EACH LIGHT SOURCE AT ANGLE ϕ WITH THE VERTICAL TO PRODUCE A MINIMUM HORIZONTAL ILLUMINATION OF 0·1 FOOT-CANDLE ON A HORIZONTAL PLANE AT GROUND-LEVEL MIDWAY BETWEEN LIGHT SOURCES

HEIGHT	10		12		14		16		18		20		25		30		35	
SPACING	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ	ϕ	I_ϕ
50	68°12′	97·6	64°22′	88·9	60°45′	84·0	57°23′	81·7	54°26′	82·3	51°20′	82·0	45° 0′	88·4	39°48′	99·2	35°32′	113·7
54	69°42′	119·7	66° 2′	107·4	62°37′	100·7	59°21′	95·3	56°18′	94·8	53°28′	94·8	47°12′	99·6	41°59′	109·6	37°39′	123·4
56	70°21′	131·5	66°48′	117·8	63°26′	109·5	60°15′	104·8	57°16′	102·5	54°28′	101·9	48°15′	105·8	43° 1′	115·1	38°40′	128·7
60	71°36′	159·0	68°12′	140·6	64°59′	129·6	61°56′	122·9	59° 2′	118·9	56°19′	117·2	50°12′	119·1	45° 0′	127·3	40°36′	139·9
64	72°42′	190·1	69°27′	166·5	66°22′	152·1	63°26′	143·1	60°38′	137·4	58° 0′	134·4	52° 0′	133·9	46°51′	140·7	42°26′	152·3
66	73° 6′	203·5	70° 1′	180·4	67° 1′	164·6	64° 8′	154·1	61°23′	147·4	58°47′	143·7	52°51′	141·9	47°44′	147·9	43°19′	159·0
70	74° 3′	240·9	71° 4′	210·8	68°12′	191·3	65°26′	178·1	62°47′	169·3	60°15′	163·7	54°28′	159·2	49°24′	163·3	45° 0′	173·2
75	75° 4′	290·2	72°15′	254·1	69°32′	229·2	66°54′	211·9	64°22′	200·1	61°56′	192·0	56°19′	183·2	51°20′	184·5	46°58′	192·7
80	75°58′	350·7	73°18′	303·4	70°43′	272·1	68°12′	249·9	65°46′	234·3	63°26′	223·5	58° 0′	210·0	53° 8′	208·4	48°49′	214·5
85	76°46′	416·8	74°15′	351·9	71°46′	319·9	69°22′	292·5	67° 3′	273·2	64°48′	259·1	59°32′	239·7	54°47′	234·6	50°32′	238·5
90	77°28′	489·3	75° 4′	420·7	72°43′	373·7	70°26′	340·8	68°12′	316·3	66° 2′	298·4	60°57′	272·9	56°19′	263·8	52° 8′	264·8
95	78° 7′	573·8	75°49′	489·4	73°35′	434·1	71°23′	393·4	69°15′	364·3	67°10′	342·3	62°15′	309·6	57°43′	295·3	53°37′	293·5
100	78°41′	661·7	76°30′	565·9	74°21′	499·2	72°15′	451·7	70°12′	416·8	68°12′	390·5	63°26′	349·3	59° 2′	330·3	55° 0′	324·6
110	79°41′	870·5	77°42′	744·7	75°43′	652·6	73°47′	587·7	71°53′	538·8	70° 1′	501·1	65°33′	440·7	61°23′	409·6	57°34′	397·0
120	80°32′	1123·8	78°41′	952·9	76°52′	835·4	75° 4′	748·0	73°18′	682·7	71°34′	632·6	67°23′	549·5	63°26′	503·0	59°45′	479·1
130	81°15′	1420·3	79°32′	1201·0	77°51′	1051·1	76°10′	936·4	74°31′	851·5	72°54′	786·7	68°58′	675·9	65°13′	610·9	61°42′	574·8
140	81°52′	1765·7	80°16′	1490·0	78°41′	1296·9	77° 8′	1159·2	75°35′	1049·6	74° 3′	963·8	70°21′	821·8	66°48′	736·1	63°26′	684·7
150	82°24′	2161·3	80°55′	1820·9	79°26′	1589·2	77°57′	1406·8	76°30′	1273·4	75° 4′	1168·7	71°34′	988·5	68°12′	878·6	64°59′	809·9
160	82°53′	2629·4	81°28′	2203·8	80° 4′	1909·2	78°41′	1694·0	77°19′	1530·5	75°58′	1402·7	72°39′	1178·4	69°27′	1040·4	66°22′	950·7
180	83°40′	3724·7	82°24′	3112·3	81° 9′	2691·2	79°53′	2361·8	78°42′	2153·3	77°28′	1957·0	74°29′	1632·3	71°34′	1423·4	68°45′	1286·5
200	84°17′	5059·1	83° 6′	4152·4	82° 2′	3681·0	80°55′	3253·2	79°48′	2917·2	78°41′	2646·8	75°58′	2191·7	73°18′	1896·4	70°43′	1700·7
220	84°48′	6716·1	83°46′	5624·9	82°45′	4875·9	81°43′	4280·6	80°42′	3838·5	79°42′	3498·8	77°12′	2873·7	74°45′	2472·8	72°21′	2197·4
240	85°14′	8713·6	84°17′	7285·1	83°21′	6310·4	82°24′	5533·0	81°28′	4958·5	80°32′	4495·1	78°14′	3684·9	75°58′	3156·1	73°44′	2786·8
270	85°46′	12430·0	84°55′	10350·0	84° 5′	8947·0	83°14′	7825·0	82°24′	7002·7	81°34′	6340·3	79°31′	5187·9	77°28′	4403·4	75°28′	3875·9
300	86°11′	16953·0	85°26′	14265·0	84°40′	12203·0	83°55′	10755·0	83° 9′	9548·1	82°24′	8645·3	80°32′	7023·6	78°41′	5955·3	76°52′	5221·3

Height is in feet from ground-level to centre of light source. Spacing is distance in feet between light sources. ϕ is angle to nearest minute that light ray makes with vertical.

In the construction of these tables the following data have been used. In Fig. 120,

$I\phi$ is the candle-power intensity of the light source at angle ϕ.
h is the height in feet of the light source above ground-level.
ϕ is the angle between the vertical and a light ray reaching the plane of reference at the mid-span position.
p is the horizontal plane on which the illumination is measured.
d is the span.

The angle ϕ can be found from the formula $\tan\phi=\frac{d}{2h}$.

The most convenient formula for the determination of horizontal illumination, usually designated E_h, is

$$E_h=\frac{I\phi\times\cos^3\phi}{h^2}.$$

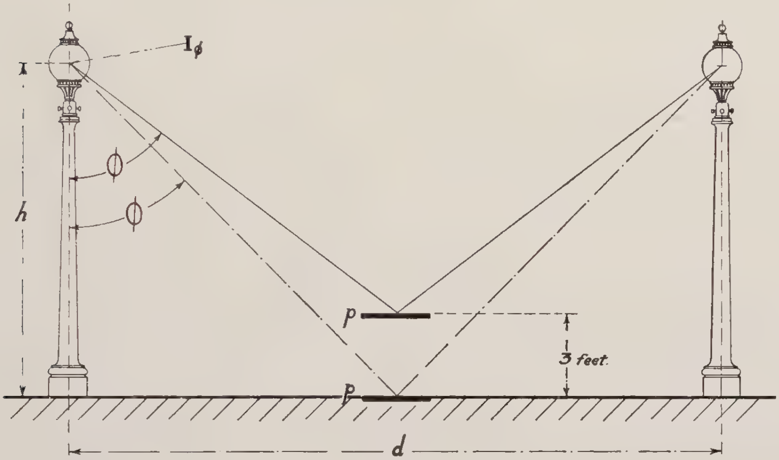


Fig. 120.

To obtain the candle-power $I\phi$ necessary to produce illumination E_h the equation must be transposed, and becomes

$$I\phi=\frac{E_h\times h^2}{\cos^3\phi}.$$

As in the case considered in the tables the horizontal illumination at the mid-span position is derived from two lamps (one at each end of the span), each contributing half, E_h must be taken as half the total value required.

In Table XX the plane of reference is 3 feet above ground-level, and it is therefore necessary for the purpose of calculation to deduct this distance from h, and the equation for horizontal illumination for this table becomes

$$E_h=\frac{I\phi\times\cos^3\phi}{(h-3)^2},$$

and the equation for the candle-power required,

$$I\phi = \frac{E_h \times (h-3)^2}{\cos^3 \phi}.$$

Although the value of the horizontal illumination given in the tables is 0·10 foot-candle, they can obviously be used for any other minimum intensity which may be required. All that is necessary is to multiply or divide the candle-power given in the tables as may be required; *i.e.* to obtain a minimum illumination of 1·0 foot-candle, the candle-power values must be multiplied by ten, whilst if only 0·025 foot-candle is necessary the candle-power values must be divided by four.

The lighting engineer can by the use of these tables ascertain in a few moments whether or not any particular lighting unit, the polar distribution of which is known, will for a given height and spacing furnish the requisite minimum illumination. Assume, for instance, a height of 18 feet and a spacing of 150 feet. Reference to Table XX shows that a candle-power of 1,489 is required at an angle from the vertical of 78 degrees 41 minutes. If, on reference to the polar curve, it is found that not less than this candle-power is available at the angle specified, then the unit can be used with the assurance that an initial minimum horizontal illumination of not less than 0·1 foot-candle will be obtained on a plane, 3 feet above ground-level, located at the mid-span position. If the polar curve cannot be referred to, the makers of the unit can be asked to furnish the candle-power at the angle in question. If the illumination is required on the surface of the roadway, Table XXI can be used in the same manner.

Diversity Factor.—The terms ‘diversity factor’ and ‘inequality ratio’ are somewhat indiscriminately used for the purpose of indicating the inequality in the intensity of the illumination over any particular surface—in the case we are considering, the surface of a street—and actually represent a ratio expressing the quotient of the maximum illumination on any part of the street or roadway, divided by the minimum illumination.

It is by no means sufficient to provide a satisfactory minimum illumination at the mid-span position, if, in order that it may be obtained, the intensity immediately under, or adjacent to, the light sources is so great as to produce along the surface of the street a series of intensely bright and comparatively sharply defined patches of light alternating with very considerably darker portions. It is no uncommon thing to find in streets so lighted a variation in the foot-candle intensity exceeding 100 to 1, and in a case recently investigated the diversity factor as ascertained by careful photometric readings was found to be no less than 186 to 1.

The permissible diversity depends very largely upon the order of illumination to be provided. Where the minimum value is high, as for instance 0·5 to 2·0 foot-candles, a comparatively large difference in foot-candles is not nearly so noticeable visually as a much smaller difference would be in a street in which the minimum intensity was materially lower. Thus a variation of from 5 to 75 foot-candles might appear reasonably uniform, whilst a range of 0·1 to 1·2 foot-candles would undoubtedly appear decidedly patchy.

This fact was very strikingly impressed upon one of the authors during the course of a series of tests conducted to determine the diversity which could safely be permitted in the illumination of an extensive advertisement hoarding. A white screen of considerable area, illuminated in such manner that the measured intensity ranged from 40 to 4 foot-candles, appeared, when viewed from a little distance, to be quite evenly lighted; but directly the intensity was reduced to a point at which the variation was from 0·5 to 0·05 foot-candle, the difference between those portions of the surface which respectively received the maximum and the minimum illumination was not only made manifest, but appeared even greater than it really was.

The practical application from the point of view of street lighting is, that in those cases where the minimum intensity is low, greater care must be taken to secure a low diversity factor than is necessary when the illumination is on a materially higher level.

The illumination over the whole of the roadway should be such as to produce a reasonably even gradation from the maximum to the minimum intensity, which (apart from shadows cast by the equipment) should not at any point be materially less than the minimum mid-span value, whilst the actual diversity factor should not usually exceed from 10 : 1 to 20 : 1, and may with advantage be materially less.

It may be of interest in this connection to state that an analysis of the results obtained in 27 recent installations of street lighting discloses the following variation in the diversity factor: minimum 3·25 : 1, maximum 56 : 1, and average 22·4 : 1.

Grading of Streets.—It will be noticed that no attempt has so far been made to indicate the types of streets to which the various suggested minimum illumination values should apply. It is difficult, if not impossible, to lay down anything in the nature of a hard-and-fast classification. So much depends, and must inevitably continue to depend, upon individual circumstances and local conditions, that it must be left to those responsible to make for themselves such classification as best meets their particular requirements.

The following is suggested as likely to be helpful when tabulating streets in this manner:—

Class A. Principal business streets,
Important traffic junctions,
Approaches to terminal railway stations, public squares, etc. etc.
Class B. Main thoroughfares.
Class C. Secondary thoroughfares and important residential roads and streets.
Class D. Less important streets.
Class E. Side streets.

Height of Light Sources.—The height at which the lights are fixed above the roadway—that is to say, the height of the overhead suspensions, brackets, or standards—is a factor of considerable moment. Whilst it is true that it is always advisable to err on the side of fixing the height of the light sources at too high a level rather than at one which is too low, if only from the point of view of diminishing the risk of 'glare,' it is necessary, if the installation is to present a pleasing appearance and prove satisfactory in service, to have regard to several considerations of importance. The majority of streets are bounded by buildings possessing in certain cases features of architectural interest or beauty, and which in every case should receive a certain amount of illumination. Upon the height of such depends, in large measure, the permissible height of the units used for their illumination, as it will readily be appreciated that the æsthetic appearance and 'balance' of a street bounded by buildings of, say, 40 feet in height might be totally destroyed if it were, for instance, equipped with lighting standards of, say, 50 feet in height, however desirable such might be from a purely illuminating point of view. The width of the street must also be regarded. Unduly short posts along a really imposing thoroughfare would appear ridiculously out of place, whilst very tall posts in a particularly narrow street would look equally absurd. Again, in residential districts many householders not unreasonably object very strongly to the use of units supported at such a height that direct rays from powerful light sources enter through second-storey bedroom windows.

Another feature of residential roads and streets is the presence of trees. Where these occur, either the units must be centrally suspended as in Fig. 107, or the height of the supporting standards must be such as to avoid undue interference from the trees when in full leaf.

Subject to such considerations, the following are recommended as satisfactory average heights for street-lighting fittings:

Type of Street or Thoroughfare	Average Mounting Height
Class A . . .	25 to 35 feet.
Class B . . .	18 to 20 ,,
Class C . . .	16 to 18 ,,
Class D . . .	10 to 14 ,,

Spacing-Height Ratio.—The spacing-height ratio—that is to say, the distance in feet between adjacent light sources, divided by the height in feet at which they are suspended or supported—should not exceed a certain maximum value if satisfactory or reasonably even lighting is desired. The span which is usually most suitable for a given height is dependent upon the angle from the vertical at which the maximum candle-power is emitted by the fitting to be used, and represents a value equivalent to twice the height of the source—above the plane of reference—in feet, multiplied by the tangent of such angle ($d=2h \tan \phi$). If undue glare effects are to be avoided, the angle at which the maximum candle-power is emitted should not usually exceed from 70 to 75 degrees from the vertical, which corresponds to a tangent of from 2·747 to 3·732, and gives a spacing-height ratio of from 5·49 : 1 to 7·46 : 1.

A spacing-height ratio ranging from about 4 : 1 as a minimum to 8 : 1 as a maximum will ensure a satisfactory compromise between economy on the one hand and efficiency on the other. If the latter value is materially exceeded it will usually prove almost impossible to avoid one or other of two serious drawbacks. Either the minimum mid-span illumination will suffer and a very high inequality ratio will result, or a beam effect will be almost inevitable, with its attendant evils of inconvenience and danger to both vehicular and pedestrian traffic due to dazzle and glare troubles generally.

Lamps.—It may be accepted as axiomatic that, other conditions being equal, the success or failure of any installation of street lighting is directly dependent upon the uniformity, the efficiency as light-producing devices not only when first installed but throughout the whole of their useful life, and the reliability of the lamps used.

Lighting service, by which is meant maximum light output for minimum consumption of electrical energy, is, or should be, the first if not the sole consideration; this being so, too much attention cannot be devoted to the selection of so all-important a component.

Once it is realized that no matter how low, within practical limits, the price paid per unit may be, the cost of the electrical energy consumed by a lamp throughout its normal life is usually many times that of the lamp itself, it becomes obvious that in this particular, at all events, quality is of supreme importance and first cost a minor consideration.

Fortunately for all concerned, the publication of the British Engineering Standard Specification No. 161 (1924) for Normal-type Tungsten-filament Electric Lamps[1] provides a means whereby the requisite standard of excellence may readily be secured; and only lamps constructed in accordance with, and complying in all respects with the terms of, this specification should be used for street lighting.

As there exists in certain quarters a disposition to regard this specification as something produced by the lamp manufacturers to cheapen their product or help their sales, it cannot be too strongly emphasized that, so far from this being the case, it is essentially a specification dictated by lamp *users* in their own interests and for their own protection. Of the twenty-one authorities who officially co-operated in its preparation, and who were actively represented on the committee which worked for over a year on its construction, only one is concerned with the manufacture of lamps. Twenty-nine members, of whom only eight represented the lamp manufacturers, comprised the committee, and it is therefore fairly obvious that even had the lamp manufacturers so desired they could not have influenced the specification in their favour.

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[1] See page 338.

The specification is admittedly a drastic one; and whilst space does not permit of the critical examination of its various provisions which their importance warrants, it may be stated that only really first-class lamps produced by reputable firms possessing the requisite skill and resources can hope successfully to meet its requirements.

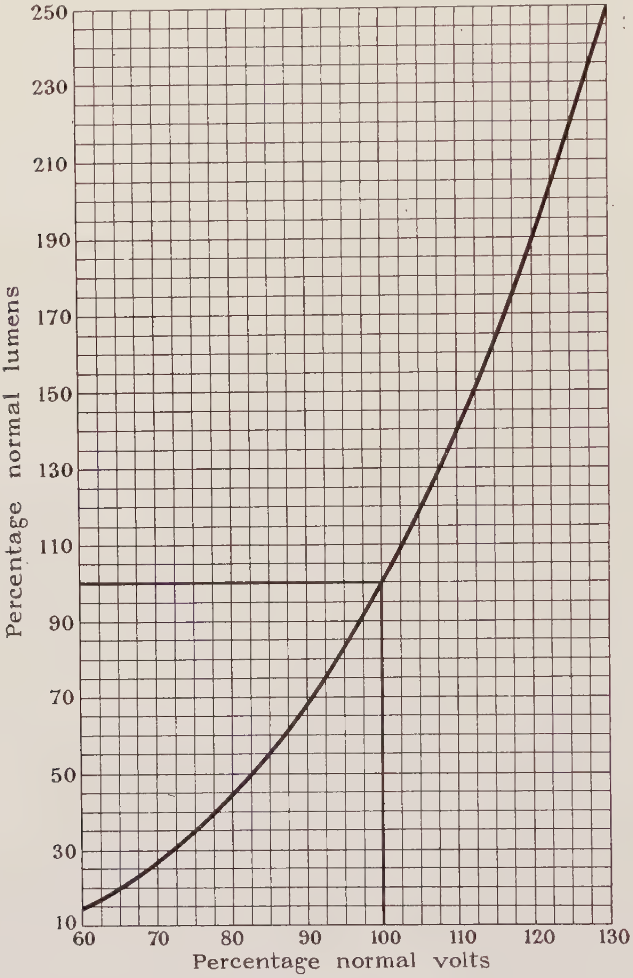


Fig. 121.—Showing Relation between Applied Voltage and Lumen Output.

The amount of light obtainable from the expenditure of a given amount of electrical energy depends upon the efficiency of the lamp, which in turn depends upon the temperature at which its filament is operated. The higher temperature at which the filaments of modern gas-filled lamps are run is, in the main, responsible for their greatly increased efficiency, which cannot, however, be realized to the full extent in practice unless the lamps are regularly run at exactly their rated voltage. A fall of 1 per cent. in the temperature of the filament reduces the light output by approximately 11 per cent.

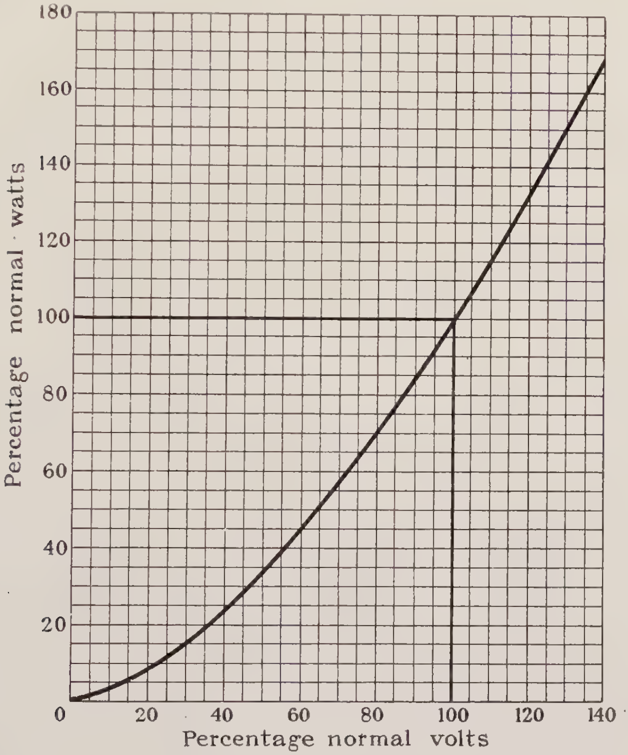


FIG. 122.—SHOWING RELATION BETWEEN APPLIED VOLTAGE AND WATT CONSUMPTION.

The relation between the terminal voltage applied to a tungsten-filament gas-filled lamp and its output of light in lumens is shown by the curve given in Fig. 121, whilst in Fig. 122 will be found a curve connecting the applied voltage with the watt consumption.

Fig. 121 shows that an increase of 1 per cent. in the applied voltage increases the light output of the lamp by 4 per cent., its consumption being at the same time increased by 1·7 per cent., as indicated by Fig. 122. That a *reduction* in the applied voltage decreases both the lumen output and the watt consumption is also shown; it is therefore apparent that not only is it advisable from every point of view to run lamps at their correct terminal voltage, but that, from the standpoint of the production of light, the practice adopted by many of deliberately underrunning them not only fails to secure any economy but actually involves an increased expenditure.

A clear understanding of this point is of such importance that an example may prove helpful.

Consider the case of a 500-watt, 200-volt lamp operated at normal voltage. The list price of the lamp is 15s. The initial lumen output is 7,110 lumens. The average lumen output throughout an average life of 1,000 hours is 90 per cent. of the initial rating—that is to say, is 6,399 lumens. The electrical energy consumed by a lamp giving 6,399 lumens for 1,000 hours equals 500 Board of Trade units, which, at a charge of one penny per unit, equals a cost of £2, 1s. 8d. The total cost of both lamp and electrical energy for a lamp giving 6,399 lumens is therefore £2, 16s. 8d., and the total cost per lumen-hour 0·000106 penny.

Now, consider the same lamp operated at, say, 10 per cent. below its rated voltage, *i.e.* at 180 volts, and assume that its life is thereby extended to 2,000 hours, a generous assumption. From Fig. 121, if a lamp is operated 10 per cent. below its rated voltage the light output is reduced 32 per cent. The lumen output is therefore only 4,351 lumens. From Fig. 122, underrunning the lamp by 10 per cent. lowers the watts consumed by 15·5 per cent. The watt consumption is therefore only 422·5 watts. The electrical energy consumed by such a lamp giving 4,351 lumens for 2,000 hours is 845 Board of Trade units, which at one penny per unit equals £3, 10s. 5d. The cost of the lamp remains at 15s., and the total cost of both lamp and electrical energy for a lamp giving 4,351 lumens for 2,000 hours is therefore £4, 5s. 5d., equivalent to a total cost per lumen-hour of 0·0001177 penny.

At this rate the total cost of lamp and energy for a lamp giving 6,399 lumens for 1,000 hours is £3, 2s. 9d. The total cost of the same amount of light under normal voltage conditions was only £2, 16s. 8d.

In other words, the light emitted actually costs 10·7 per cent. more when a 500-watt, 200-volt lamp is operated at a terminal voltage 10 per cent. below the rated voltage of the lamp.

Under similar conditions the increase in the cost of the actual light obtained is, for a 1,000-watt lamp, 14·1 per cent., and for a 1,500-watt lamp, 15·1 per cent.

If the price of the lamp itself is reduced, as would normally be the case owing to the discount off the list price which would presumably be granted, then the increase in the cost of the actual light obtained from an underrun lamp is even greater.

Granting, then, the desirability, if not essentiality, of running every lamp at not less than its full rated voltage, how is this requirement to be met under practical working conditions ?

Reference was made, when discussing the question of available systems, to a method of feeding a parallel circuit, supplying a considerable number of lamps, in such manner as to reduce the voltage drop in the cables to the minimum. Much can be done, and everything possible should be done, in this direction, but even careful attention to this point alone is insufficient to ensure the most satisfactory results.

From the point of view of maximum efficiency the ideal method would be to number the posts consecutively, to ascertain the exact voltage at the *top* of every individual post, and to use on each a lamp constructed to operate at maximum efficiency at that particular terminal pressure. Such procedure would, however, involve the ordering of numbers of lamps of unusual and non-standard voltages, would introduce complications into the storage of the lamps by the lighting authority, and would entail the by no means inconsiderable risk of a lamp of incorrect voltage being inserted into any particular lamp-holder.

For these reasons a preferable method, from a practical point of view, is the insertion in series with each lamp of a resistance designed to carry continuously the current taken by the lamp and capable of adjustment in such manner as to ensure each lamp operating at its correct voltage. The voltage at which the individual lamps must be adjusted to operate will naturally be the nearest standard voltage *less* than that prevailing at the point on the circuit at which the drop is greatest. The resistance can be housed in the base of the standard, and the correct voltage, which should always be measured across the actual lamp terminals and not at the base of the standard, determined by a voltmeter.

A method resulting in even greater uniformity, by reason of the fact that it takes into consideration and eliminates both lamp tolerances and small variations in individual lanterns, is so to adjust the terminal voltage of each lamp by means of the resistance that the resultant illumination measured at some standard distance from the lamp-post is the same in every case. The lumen output of each lamp would then be substantially identical, and the lamps when burning would present an even appearance such as cannot be obtained on a parallel circuit by any other means. The cost of such resistances is very little, the space which they occupy is quite small; since the slight inefficiency introduced by their use is very much more than offset by the greatly improved appearance of the installation as a whole, the method is worthy of adoption, more particularly in those cases where a pleasing appearance is of special importance.

Lanterns.— The lanterns or fittings commonly used for the purpose of street lighting may be divided into three broad groups. These are : (*a*) converted arc lamps, of one or other of the various types formerly used for street illumination; (*b*) lanterns of what may be termed the ‘ housing ’ type, in which little or no attempt is made more than to enclose, or house, the actual lamps; (*c*) scientifically designed street-lighting lanterns, produced by those experienced in the technique of street-lighting, and in the design and construction of which due regard has been paid to the specific purpose for which they are intended to be used.

Before discussing these groups in detail, it may prove helpful to define those qualities which completely satisfactory street-lighting lanterns should possess. Reference will be made to many of these when dealing with the respective groups, but they may be briefly stated at this stage as follows :—

The external appearance and proportions should be sufficiently pleasing to permit of their general adoption.

The durability should be such as to ensure long and satisfactory service under the most adverse climatic conditions likely to be experienced.

The weather-proof qualities should be such as effectually to prevent the entrance of water under all conditions of driving rain or hail, drifting snow, or prolonged mist.

The ventilation should be such that, in addition to complying with the previous conditions, the internal temperature, at the end of the longest period for which they are required to burn, and when using the highest wattage lamp which can be accommodated, will be such that the lamp remains so cool that both its normal life and its candle-power throughout life are unimpaired.

The focussing adjustment should be capable of operation with one hand without opening the lantern, should be such as to permit of the filament of either the smallest or the largest lamp which can be accommodated being brought into the correct position, and should preferably be of a type capable of eliminating variations in the position of the filament in individual lamps due to manufacturing tolerances.

The accessibility of portions which require periodical removal or renewal, as for instance the lamp or glassware, should be such as to ensure easy operation.

The rays from the source should be directed in such manner as to ensure that the light is correctly distributed on the surface of the street.

(*a*) **Converted Arc Lamps.**—The by no means unnatural desire of street-lighting engineers to eliminate the difficulty and expense of the frequent trimming and cleaning of arc lamps—to say nothing of the cost of carbons—and to secure for themselves the advantages and reliability of the high-wattage gas-filled lamp, has led, in many cases, to the conversion of the former. The object is, of course, to avoid the expense of new equipment, but, allowing to the fullest extent for whatever small saving may be effected, the practice has nothing to recommend it, and from the standpoint of efficient street lighting has many drawbacks.

The usual method is to remove, wholly or in part, the interior mechanism of the arc lamp, and to fix in its place a Goliath Edison screw lamp-holder, in which the gas-filled lamp is inserted and which is connected to the original terminals. The outer globe of the arc lamp is in some cases retained and in others discarded. If such does not already form part of the arc-lamp casing, an over-reflector, usually of vitreous enamelled steel, is frequently added. The cost of such conversion is generally at least half, and is frequently almost as great as, that of a new lantern of suitable type, whilst the result is a hybrid contraption possessing neither beauty nor efficiency, and which, as will be shown, proves, light for light, considerably more costly in the long run.

The two polar curves in Fig. 123 show respectively and to the same scale the light emission in a vertical plane from a converted arc lamp and that from a street-lighting lantern of modern type, the make, wattage, voltage, and type of lamp being similar in each case. The arc lamp to which the dotted-line curve relates is one of a considerable number converted for one of the larger London boroughs. In this case the opalescent glass arc-lamp globe was discarded on account of light absorption, and an over-reflector fitted for the purpose of securing increased dispersion. The lantern, the light emission from which is shown by the solid-line curve, is of the type installed by the borough electrical engineer of Barnes for the illumination of the main road from Hammersmith to Richmond.

It is obvious from the shape of the dotted curve that the converted arc lamp is fundamentally unsuitable for street lighting. An examination of the polar curves discloses the fact that the angle at which the maximum candle-power is emitted is for the converted arc lamp only 15 degrees, and for the comparative lantern 70 degrees, from the vertical. This means that if the light rays of maximum intensity are to strike a horizontal plane of reference 3 feet above the ground at or near the mid-span position, as they undoubtedly should if the minimum diversity is required in the resultant illumination on such plane, the converted arc lamps would require to be spaced a distance apart equivalent to approximately half their height above the plane of reference, whereas the comparative lanterns could be spaced at approximately six times their height above such plane.

A spacing of half the height is so obviously impossible in practice that we must therefore consider what would happen if in both cases the spacing was such that a light ray emitted at the customary angle of 70 degrees from the vertical struck the plane of reference at the mid-span point. It will be seen that in such case the candle-power of the respective rays would be for the converted arc lamp 625 and for the comparative lantern 1,528. In other words, the candle-power from

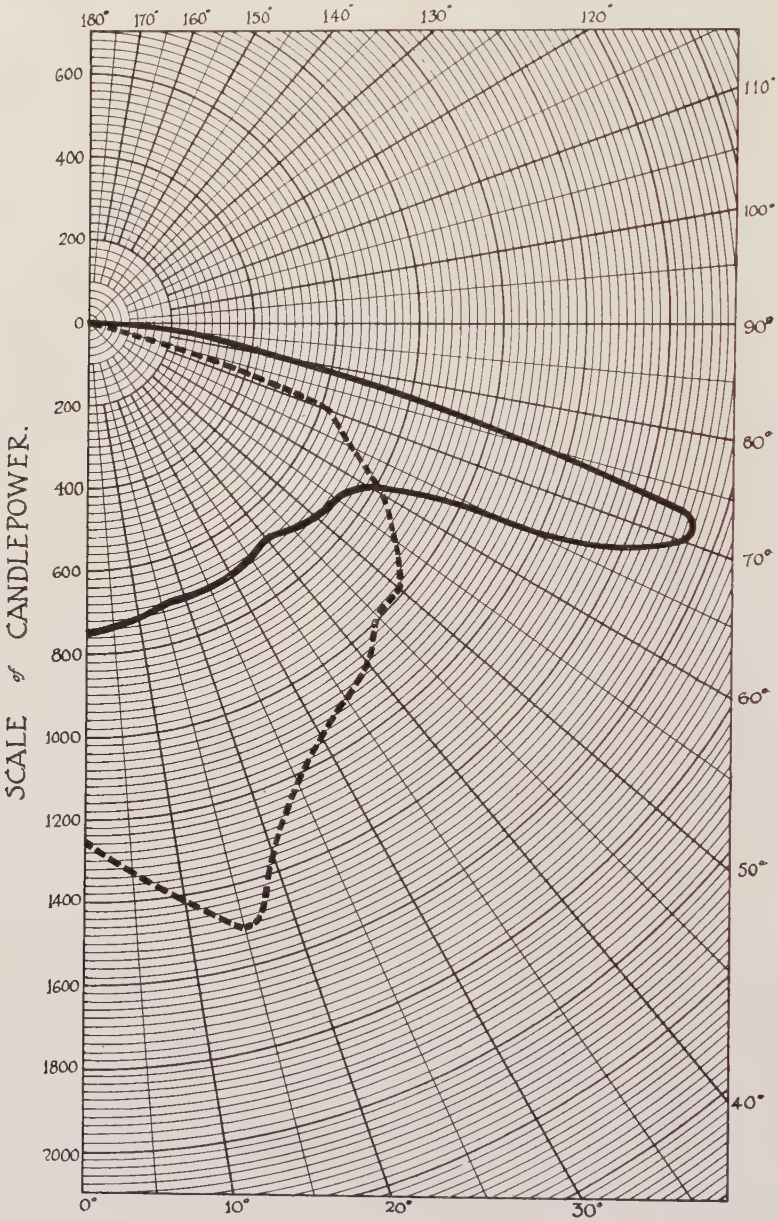


FIG. 123.—COMPARATIVE POLAR CURVES. (*a*) Converted arc lamps (dotted line); (*b*) modern street-lighting lantern (solid line).

the comparative lantern at the angle in question is no less than approximately 145 per cent. greater than that from the converted arc lamp; and as the latter by no means represents the worst of its class in use at the present time, the fallacy of sinking money in such conversions is immediately apparent.

Lest it might be thought that the instance cited was exceptional in character, it may be stated that the public lighting of an important health resort was, after investigation by one of the authors, modernized by the removal of the converted arc lamps previously used and the installation in their stead of scientifically designed lanterns. In this particular case, which is typical of others, the lanterns are suspended at a height of 21 feet and are spaced at distances varying from 200 to 230 feet apart. Dealing with the space between two adjacent columns, the maximum illumination was increased by 60 per cent., the average illumination by 200 per cent., and the minimum illumination at the mid-span position by no less than 400 per cent. The diversity factor was at the same time decreased by 68 per cent., with the result that the improved illumination was not only considerably greater but materially more even. The values given represent in each instance the increase in the foot-candle intensities actually measured on a horizontal plane 3 feet above ground-level.

(*b*) **Lanterns of the Housing Type.**—This is the group in which by far the greater proportion of the lanterns put forward as suitable for street-lighting purposes, and which are still being largely sold to those without sufficient experience, must unfortunately be placed. Such lanterns amount in many cases to little more than a housing or covering for the actual lamp, and, although superior to converted arc lamps, are as a class conspicuous by the absence of anything in the nature of correct and effective distribution. Their only virtue is their low first cost, and, in order that this may be reduced to the minimum, materials are often used in their construction—such as, for instance, light-gauge sheet-iron—which are incompatible with obtaining the durability and satisfactory service reasonably expected from street-lighting equipment.

The weather-resisting properties of lanterns of this type are frequently quite inadequate, and many lamp failures have been found to be due entirely to their inability to prevent the entrance of rain, hail, or snow, especially when propelled by a driving wind of considerable force. When it is realized that the falling of even a single drop of water upon a hot gas-filled lamp almost inevitably results in the failure of the latter due to the cracking of the bulb, the importance of any defect in this direction will be appreciated. Apart altogether from this particular failing, the ventilation of such lanterns is usually not only unsuitable in character, but is insufficient to permit of the successful use of high-wattage lamps.

A group of some of the more satisfactory types of lanterns of this class is illustrated in Fig. 124, from which an idea of their appearance and construction can be obtained.

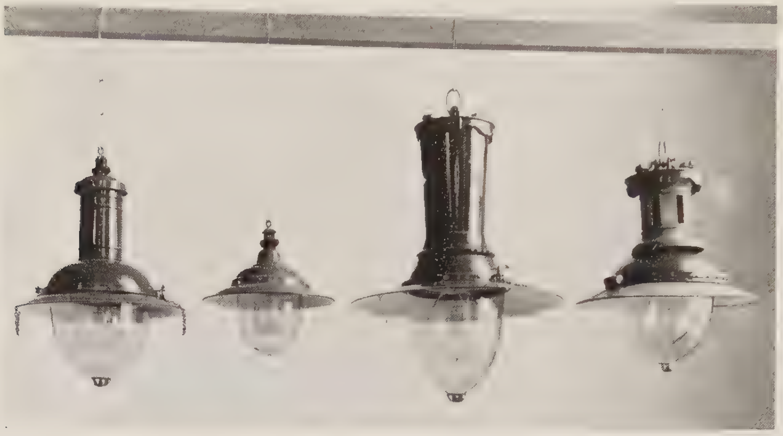


Fig. 124.—Group of Lanterns of the Housing Type.

In Figs. 125 and 126 are shown, drawn to the same scale, the polar curve of the lantern shown at the extreme left-hand side of Fig. 124, and that of a scientifically designed lighting unit which will be dealt with at a later stage. These curves show the light emission in a vertical plane obtained from the respective lanterns when

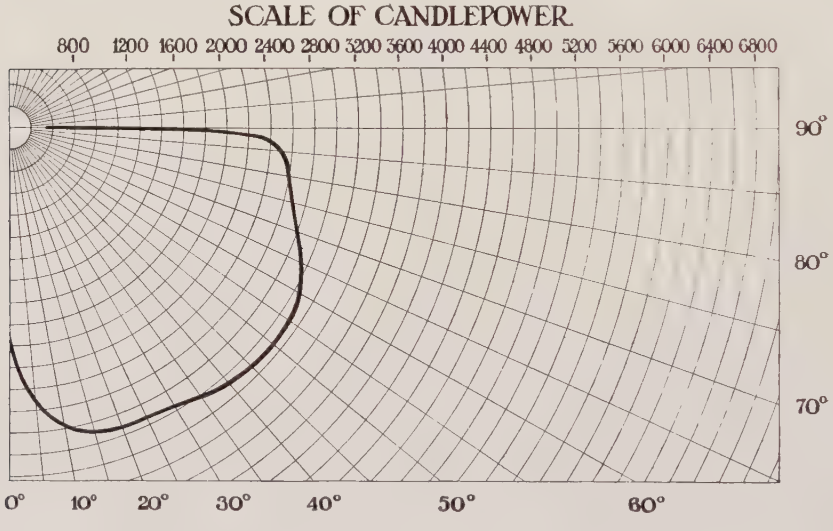


Fig. 125.—Polar Curve of Lantern of Housing Type.

equipped with a 220-volt, 1,500-watt gas-filled lamp. It will be seen from Fig. 125 that the maximum candle-power of 3,135 is emitted at an angle of 50 degrees from the vertical. This angle, although very much more satisfactory than the 15-degree angle of maximum emission for the converted arc lamp shown in Fig. 123, is by no means sufficient for economical and efficient street lighting, and compares very unfavourably with the angle of 70 degrees from the vertical shown in Fig. 126. A comparison of the two curves shows that, not only is the angle of maximum emission of the scientifically designed unit more satisfactory, but the intensity at such angle is more than twice as great—actually 113 per cent. greater.

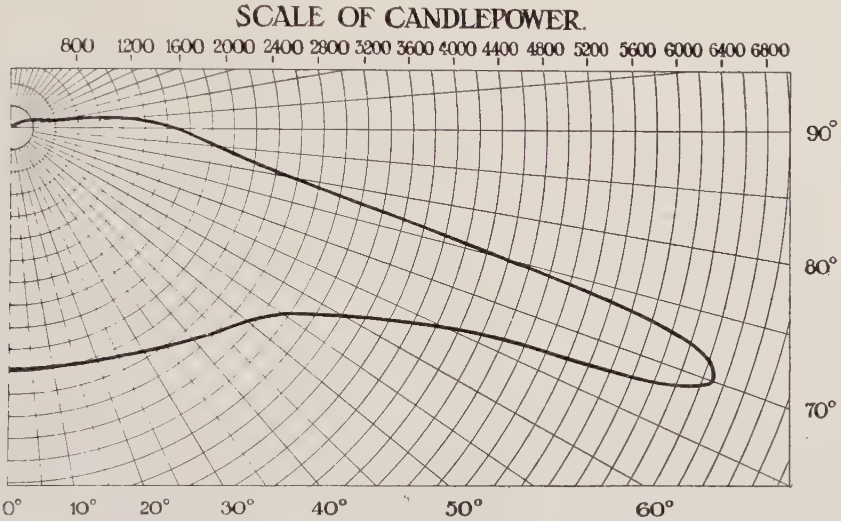


Fig. 126.—Polar Curve of scientifically designed Lighting Unit.

The practical effect of such a variation in the manner in which the light flux is emitted is strikingly illustrated in Fig. 127, in which is shown, in the form of two curves, the illumination which would be obtained between two lanterns of each of the types which we are considering, suspended or mounted, at a height of 25 feet from ground-level to lamp filament and spaced 120 feet apart. The broken-line curve shows the illumination obtained from two lanterns, each having the light emission shown in Fig. 125, and the solid curve that from two lanterns having the emission shown in Fig. 126. The foot-candle intensities shown represent in each case the horizontal illumination which would be received along a straight line between the lanterns and upon the horizontal plane 3 feet above ground-level. As the lamp used in the preparation of the two polar curves, a 220-volt, 1,500-watt gas-filled 'Osram' lamp, having an initial light output of 1,927 mean spherical candle-power, or 24,222 lumens, was the same in each case, both the polar curves and the resultant illumination curves are strictly comparable. The cross-hatched portion in Fig. 127 represents the gain in the illumination obtained from the more satisfactory units over the central 60 feet of the span, where the increased intensity is of the greatest practical value, and it is interesting to note that not only is the minimum mid-span illumination increased from 0·47 to 1·06 foot-candles, a gain of approximately 126 per cent., but that the diversity factor is at the same time reduced from 12·3 : 1 to 4·3 : 1, a decrease of 65 per cent.

When it is considered that the materially higher and considerably more even illumination shown is obtained from the expenditure of exactly the same electrical energy, and that this particular advantage, important though it undoubtedly is, represents only *one* of a number secured by the use of scientifically designed equipment, the failure of those responsible to realize as they should that lanterns of the 'housing' type are expensive luxuries, no matter how low their first cost may be, is difficult, if not impossible, to explain.

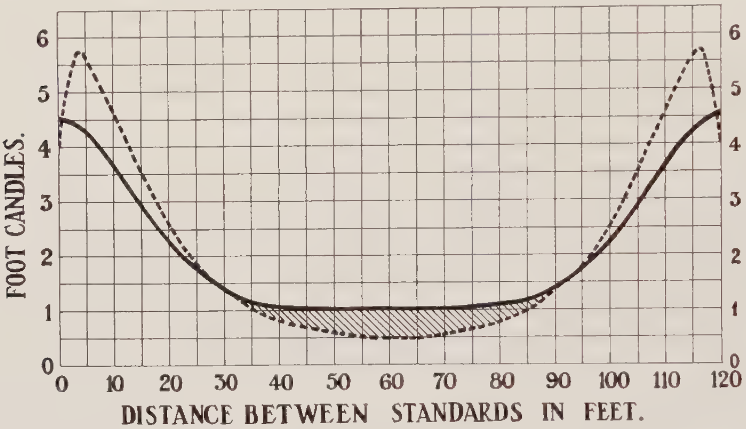


Fig. 127.—Illumination Curves from Units the Light Emission from which is shown in Fig. 125 and Fig. 126.

(*c*) **Scientifically Designed Street-Lighting Lanterns.**—Of the comparatively few scientifically designed lanterns available for street lighting, that known as the 'Wembley' lantern stands alone. This lantern, recently referred to in the editorial columns of one of the leading organs of the electrical press as 'the famous Wembley lantern,' probably approaches more closely to the ideal than any other, and as many of the features embodied in its design and construction are unique in character and are typical of the lines which the development of street-lighting equipment should follow, it may be of interest to consider them in detail.

The external appearance of the lantern complete with glassware is shown by the photograph reproduced in Fig. 128, whilst the sectional elevation in Fig. 129 makes clear the arrangement, construction, and easy accessibility of the component portions. The outer casing and over-reflector are of stout sheet-copper, which possesses the advantage that it cannot rust, and offers greater resistance than most materials to the deleterious action of either the salt-laden winds of coastal towns or the impure atmosphere of many industrial areas. The lantern can be screwed directly to a bracket or harp, or suspended by an insulating shackle. For the latter purpose the combined insulating shackle and weather-proof connecting-box shown in the illustrations is provided. The lantern is, as all lanterns should be, supplied complete with internal wiring. The leads from the lamp-holder are protected by a flame-proof and heat-resisting braiding of asbestos, and are securely soldered to two substantial metal contact pieces in the connecting-box under which the ends of the external leads are clamped. The connecting-box is provided with an easily removable front (the junction between which and the box is rendered water-proof by a flat rubber ring), and the lantern can therefore be connected or disconnected both easily and quickly, a point of importance when it is remembered that this operation has usually to be performed from the top of a long ladder.

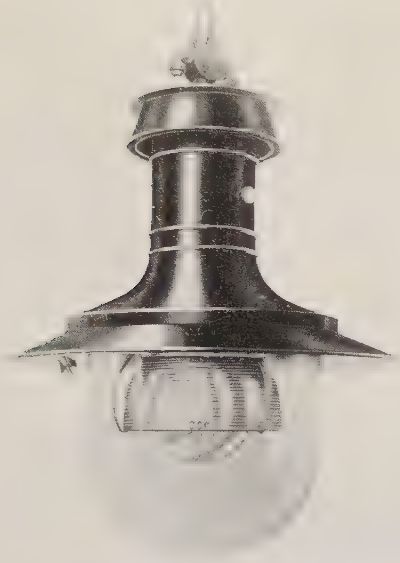


FIG. 128.—'WEMBLEY' LANTERN FOR STREET LIGHTING.

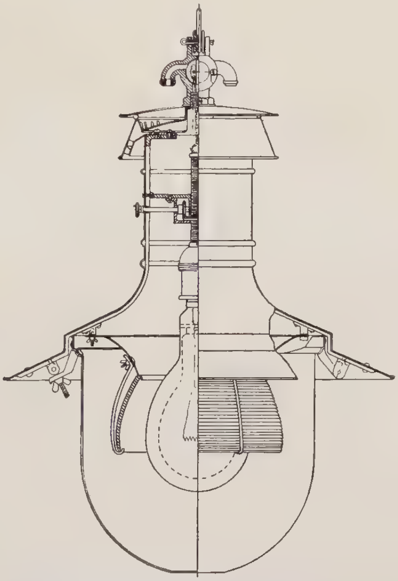


FIG. 129.—SECTIONAL ELEVATION OF 'WEMBLEY' LANTERN.

The system of ventilation is of special interest. The fact that when using a high-wattage gas-filled lamp a considerable amount of heat must necessarily be disposed of is frequently overlooked. In the case of, for instance, a 1,500-watt gas-filled lamp an amount of energy equivalent to approximately two horse-power is dissipated in the form of heat during the whole of the time the lamp is burning. To dispose of this at a rate sufficiently rapid to prevent overheating the lamp, and thereby reducing considerably both its useful life and its candle-power output, involves either the use of a radiating surface of such an area as to render the lantern very much larger and more cumbersome than any of those commonly used in this country, or an unusually effective method of ventilation such as is provided in the example under consideration. The securing of a sufficiently effective ventilation is complicated by the fact that although the outlet must be large it must be arranged in such manner as to prevent the egress of hot air being diminished by external wind pressure, or the ingress of wind-driven rain, sleet, or snow.

The patented ventilating top operates on the ejector principle, and combines extreme simplicity with high efficiency. An examination of Fig. 129 will make clear the action of the device, which causes a steady stream of air to be drawn into the lantern and ejected from beneath the upper cowl. This method possesses the very great advantage that increase in the external wind pressure increases the rate of the air-flow through the lantern, and so improves the ventilation rather than the reverse. Considerable ingenuity is shown in the manner in which the circulation has been arranged to create a ‘ stream-line ’ flow, the cool air entering at the bottom of the outer globe and being drawn directly over the neck of the lamp and the lamp-holder, the two portions particularly susceptible to overheating.

Exhaustive tests have established the fact that not only is the circulation, even in still air, sufficient to prevent either the normal life of the lamp or its candle-power output being reduced by overheating, but that the weather-resisting properties are of a remarkably high order. Two such of a somewhat unusual nature are of considerable practical interest. Two 1,500-watt lamps exhausted to the same value, and of as nearly as possible identical candle-power, were, after being carefully photometered, put into operation, one in the lantern, and the other on a test rail in a spacious room in the laboratory. Both were run continuously under controlled conditions for 1,000 hours, during which time they were photometered at intervals for the purpose of determining the drop in their candle-power. The results showed that during the first 600 hours the lamp in the lantern actually lost slightly less in candle-power than the one burning on the test rail. From this time onwards the drop was approximately equal in both lamps, and amounted to about 15 per cent. at the end of the 1,000-hours test, at which time both lamps were burning satisfactorily.

The second test, illustrated in Fig. 130, was undertaken to demonstrate the ability of the lantern to withstand the severest weather conditions. A standard lantern, suspended in a glass-sided tank, was bombarded by a number of jets of water, at 85 lbs. pressure, arranged to strike the upper portion of the casing at various angles. The many visitors to the British Empire Exhibition at Wembley who saw this lantern burning under the conditions described may be interested to learn that not a single lamp failure was experienced during the entire run of the Exhibition, apart from those of lamps which had exceeded their normal life of 1,000 hours.

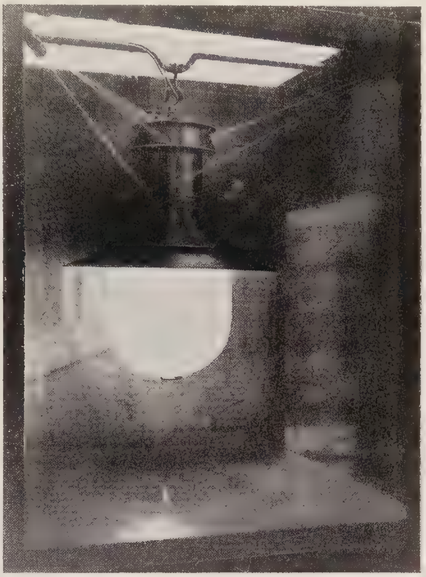


FIG. 130.—SHOWING 'WEMBLEY' LANTERN BURNING WHILST BOMBARDED BY JETS OF WATER.

The focussing device is worthy of attention. The turning of the milled knob at the side of the outer casing actuates the bevel gear shown, and this in turn raises or lowers the central screwed tube to which the lamp-holder is attached, and thus alters the position of the lamp filament in relation to the glass refractor. It should be noted that such focussing as may be necessary can be performed with one hand and without opening the lantern. The device has also the advantage of enabling variations in the position of the filament in individual lamps to be allowed for. The use of any type of prismatic glass refractor presupposes the location of the lamp filament at a definite focal point, which, although differing for various angles of maximum emission, must for any particular emission remain always the same. Owing, however, to the wide manufacturing tolerance allowed, the position of the light centre may vary in individual lamps by an amount more than sufficient seriously to impair the performance of the refractor. In the 'Wembley' lantern this difficulty is overcome by first lowering the lamp until the lower edge of the filament is seen to be in line with the bottom of the refractor, and then raising it into the correct focal position by turning the focussing knob in a clockwise direction for a certain number of turns. Using, for instance, a 1,000-watt 'Osram,' zig-zag filament, gas-filled lamp, the knob is rotated twenty-seven times for an angle of maximum emission of 70 degrees, sixteen times for an angle of 75 degrees, and six times for an angle of 80 degrees.

The single-piece prismatic glass refractor is carried by three supporting clips, spaced 120 degrees apart and arranged to obstruct the minimum amount of light. These clips are provided with a slotted portion at the upper end, and are locked in position by a substantial brass wing nut. By slackening the three nuts and lowering the clips slightly the refractor can be removed or replaced with the greatest ease; and as the internal diameter of the upper portion is greater than that of the lamp bulb, there is no necessity to remove the latter.

The outer globe of clear glass is carried in a metal ring hinged to the lantern body, is arranged to swing clear of the refractor and lamp, and is secured in position by two large brass wing nuts.

The performance of the 'Wembley' lantern is, as might be expected, of an unusually satisfactory order. Fig. 131 shows a polar curve of a single lantern equipped with one 1,500-watt, 220-volt, zig-zag filament, 'Osram' gas-filled lamp, single-piece prismatic glass refractor, and clear-glass outer globe. The light emission is ideal for street lighting, the maximum candle-power of 6,680 being given at the useful angle of 70 degrees from the vertical. The resultant illumination from two such units suspended at a height of 25 feet from the ground and spaced 100 feet apart is shown by the curve, Fig. 132. The values shown are obtained on a horizontal plane 3 feet above ground-level, and it will be seen that the maximum illumination occurs at the base of the standards, and is 4·55 foot-candles. The minimum illumination is 1·35 foot-candles, and the average intensity 2·51 foot-candles. Thus, with a spacing ratio of 4 : 1, which is in accordance with the best modern practice, an

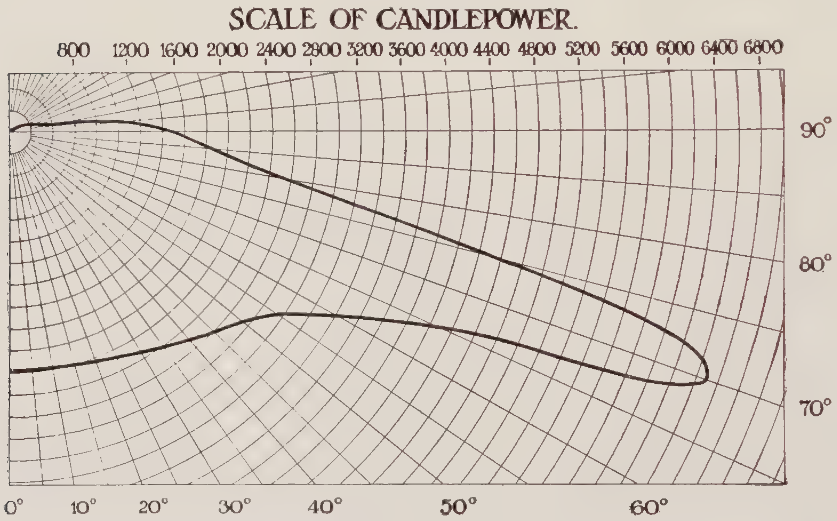


Fig. 131.—Polar Curve of 'Wembley' Lantern equipped with 1,500-watt 'Osram' Gas-filled Lamp.

inequality ratio (*i.e.* maximum illumination divided by minimum illumination) of 3·37 : 1 is obtained—a highly satisfactory figure.

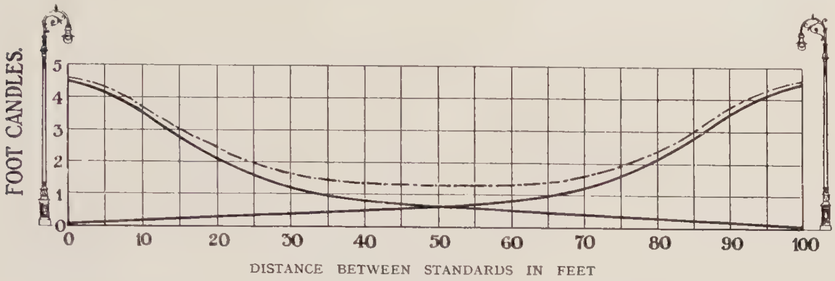


Fig. 132.—Curves showing Illumination from two 'Wembley' Lanterns.
Illumination from single lanterns is indicated by continuous line, and that from both lanterns by dotted line.

Methods of Light Control.—The candle-power distribution of the standard gas-filled lamp is inherently unsuitable for street lighting.

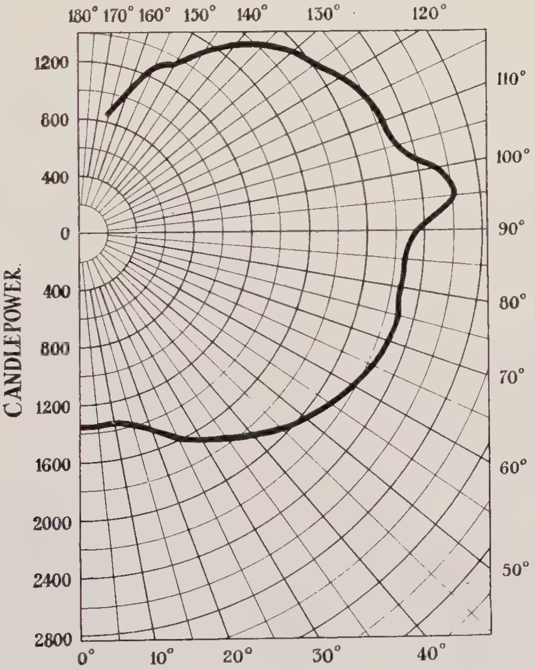


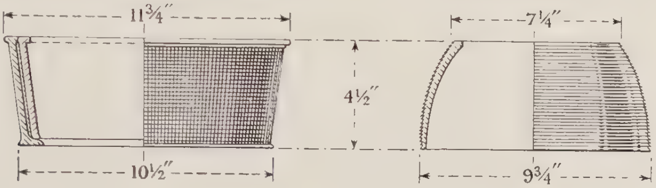
Fig. 133.—Polar Curve of 1,500-watt Gas-filled Lamps.

Fig. 133 shows the polar curve of a bare 1,500-watt, 220-volt, gas-filled lamp, having an initial light output of 2,026·9 mean spherical candles, which may, as regards its characteristic shape, be looked upon as typical of the light distribution given generally by lamps of this description. It will be seen that the distribution is unsatisfactory inasmuch as the maximum candle-power of 2,622 is emitted at an angle of 95 degrees from the vertical, which means that, unless redirected by some suitable methods, such rays would never contribute to the illumination of a horizontal surface. In order to ensure the most effective illumination of such a surface it is necessary not only to utilize as large a proportion as possible of the total light flux, or lumen output, of the lamp, but to arrange for the greater part of this to be transmitted in a particular direction in order that the maximum candle-power may have a high value and may be emitted at an angle which will permit of it reaching the street-level, or that of the plane of reference, at, or near to, the mid-span position, which means, in most cases, at an angle of about 70 degrees from the vertical.

The necessary redirecting of the light rays can be effected by either reflection or refraction, but, owing to the difficulty of providing reflectors, whether of mirror glass or surface-silvered metal, capable of successfully withstanding, without deterioration, the prolonged heat to which they must necessarily be subjected when used in close proximity to high-wattage gas-filled lamps, the latter is usually the more permanently efficient method.

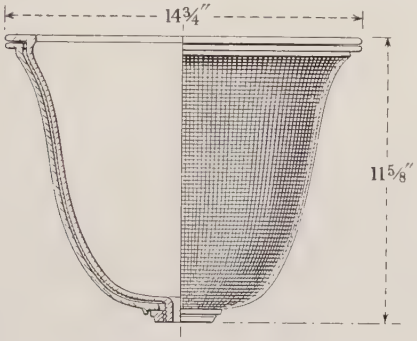
The prismatic refractors normally used for street lighting are of three types: (*a*) the double-bowl type, in which the lamp is almost completely enclosed by a glass bowl made up of two separate portions, an inner and an outer, provided respectively with radial and transverse prisms, and which are assembled together to form a single unit; (*b*) the double-band type, which consists of a nearly cylindrical band, made up of two separate portions and of the same general prism construction as that of the double-bowl type; (*c*) the single-piece bowl type, used round the upper portion of the lamp. The construction, contour, approximate over-all dimensions, and relative weights of typical refractors of each of these types designed for use with a 1,000-watt lamp are shown in Fig. 134, in which the three examples are drawn to the same scale.

It will at once be apparent that from the lighting engineer's point of view refractors of the single-piece bowl type possess many advantages. Their size and weight are less, and their initial cost is consequently materially lower—an item of no small importance when considered from the point of view of the cost of renewals. They are considerably less prone to troubles due to the cracking of the glass, owing to the fact that the temperature is more evenly distributed around them and that the temperature gradient in the glass itself is lower than that usually prevailing in two-piece bowls, or bands, in which the inner portion may be exceedingly hot and the outer relatively cold, a condition experienced at its worst, from the point of view of mortality of glassware, during spells of cold rain, snow, or hard frost. Their light absorption is necessarily less and their efficiency consequently greater than that of any two-piece refractor, by reason of the fact that, whilst undergoing refraction, the light rays pass through only one thickness of glass instead of two. They refract, and use for directional purposes, only the upper hemispherical light rays, and neither reduce by absorption, nor alter or affect in any way, the lower hemispherical light from the lamp, a feature of importance to those desirous of combining the best features of contrast lighting with the securing of a reasonably high minimum mid-span illumination. The spherical shape to which their inner surface is moulded avoids, as far as possible, undesirable internal reflections, and ensures the light rays penetrating the glassware at an angle normal to its surface.



TWO-PIECE BAND TYPE.
WEIGHT = 6 LBS.

SINGLE-PIECE
INVERTED BOWL TYPE.
WEIGHT = 3 LBS. 2 OZS



TWO-PIECE BOWL TYPE. WEIGHT = 26 LBS.

Fig. 134.—Typical Prismatic Glass Refractors.
The three examples are drawn to the same scale. The relative weights should be noted.

The manner in which, and the extent to which, a really efficient refractor of this type modifies the light distribution of the bare lamp is strikingly illustrated in Fig. 135, which shows the change in the bare-lamp curve effected by the use of the single-piece prismatic refractor employed in the 'Wembley' lantern. Not only is the angle of maximum emission changed from 95 degrees to 70 degrees from the vertical, but the value of the maximum candle-power is increased by no less than 155·5 per cent.

Influence of Size and Shape of Lamp Filament on Resultant Illumination.—Reference to page 23 of British Standard Specification

(No. 161, 1924)[1] for Normal-type Tungsten-filament Electric Lamps discloses the fact that whilst, among other items, the position in which the filament of any gas-filled lamp is to be fixed is defined within certain manufacturing tolerances, the actual size and shape of such filament is left to the discretion of the individual manufacturer.

The nature and extent of the influence which the size and shape of the filament of any lamp, and especially of any lamp used in conjunction with a reflector or refractor, have upon the light emission of the unit, and so upon the resultant illumination, is but little realized and rarely recognized. In street lighting in particular, however, the matter is of such moment that it is important that it should be correctly understood.

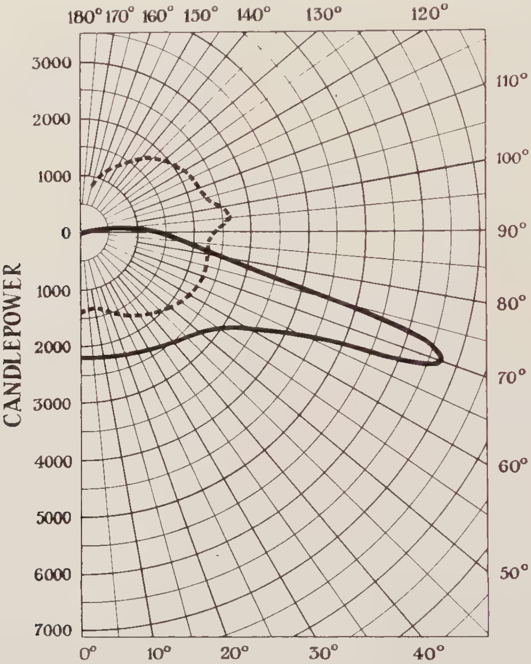


Fig. 135.—Showing change in Bare-Lamp Curve effected by the Single-piece Prismatic Glass Refractor used in the 'Wembley' Lantern.

In Fig. 136 are shown polar curves of four lamps, each of identical mean spherical candle-power, operated at the same voltage, run under controlled conditions, and used in conjunction with a single-piece prismatic glass refractor of the type shown in Fig. 137. Although giving exactly the same lumen output, each of these lamps had a filament of a different size or shape.

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[1] See page 338.

In each case the lamp was so adjusted in its relation to the refractor as to give the maximum emission at an angle of 70 degrees from the vertical. The curves differ considerably from the point of view of their usefulness for street-lighting purposes. If, for instance, the curves given by lamps A and D are compared it will be seen that the maximum candle-power of the former at the 70-degree angle, where the increase is of greatest value, is no less than 35·4 per cent. greater than that of the latter. It will also be noticed that the candle-power vertically beneath the lamp (0 degree), where the increased light is of least value, is in the case of curve D 87·5 per cent. greater than in curve A.

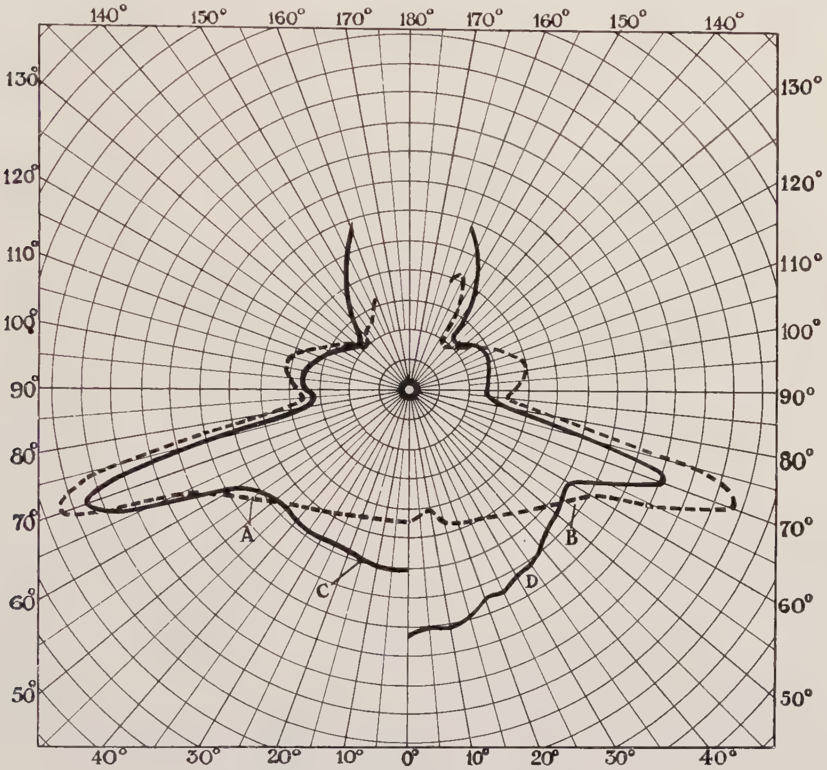

Fig. 136.—Polar Curves illustrating the Influence of the Size and the Shape of the Lamp Filament.

If, therefore, a lamp having a filament giving a curve similar to curve D were substituted for a lamp having a filament giving a curve similar to curve A, all other conditions remaining unaltered, the mere fact of such exchange would result in the candle-power being greatly diminished at the point where it is of most value, and greatly increased at the point where it is of least value.

The extent to which such a variation in light emission would affect the resultant horizontal illumination is shown by the two illumination curves in Fig. 138. In these curves the intensity of the horizontal illumination shown is calculated from polar curves A and D respectively, the solid line showing the values given by the former and the dotted line those given by the latter. In each case the height of suspension is assumed to be 18 feet and the plane of reference 3 feet above ground-level. If two lamps and refractors were spaced at such distance apart that the 70-degree ray from each met on the plane of reference at the mid-span position, *i.e.* 82·4 feet apart, equal to a spacing-height ratio of 4·5 : 1, then if lamps of type A were replaced by lamps of type D the minimum mid-span illumination would be reduced by approximately 27 per cent., the maximum illumination immediately beneath each of the posts increased by 86 per cent., and the diversity factor increased by 155 per cent. In other words, the illumination would be much more uneven and much less satisfactory.

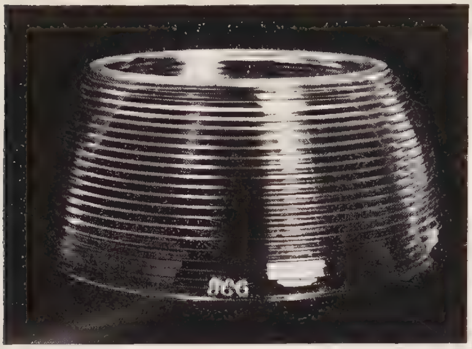

Fig. 137.—G.E.C. Single-piece Prismatic Glass Refractor.

From the consideration of these facts two points emerge: (*a*) that, other considerations being equal, the requirements of the lighting engineer in the matter of equipment are likely to be most satisfactorily and completely met by firms manufacturing *both* lamps and lanterns, and possessing research facilities and photometric apparatus of such a nature as to enable them to correlate the performance of both these items; (*b*) that having designed an installation correctly and installed a suitable equipment, neither the type nor the make of the lamps used should in any circumstances be changed without first ascertaining that the proposed substitution can be made without adversely affecting the resultant illumination. The latter point is of special importance, as unless considerable care is exercised in this respect the excellence of an installation may be completely destroyed through the purchase and use of lamps unsuitable in this particular.

Glare.—The evils of glare, and the manner in which they may all unwittingly be introduced, have already been touched upon. Glare is of many kinds, is attributable to many causes, and is not only bound up indissolubly in the question of contrast, but depends to a considerable extent upon the intensity of the illumination as a whole. A lamp, or fitting, which, used in a well-lighted thoroughfare and viewed against a background of reasonably illuminated buildings, appears quite free from glare, may, if used in a thoroughfare in which the intensity is very much lower, or in which it can only be viewed against a dark background such as the night sky, give the impression of pronounced glare. Again, fittings at a height and spacing which may be quite free from glare when used along a level street or road may appear glaring if used upon an appreciable incline.

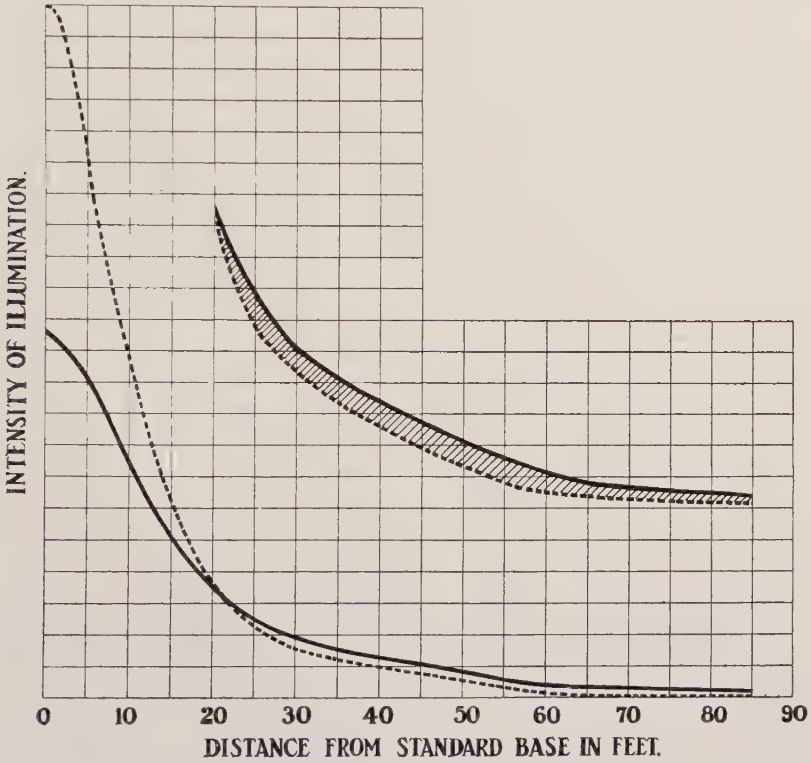

Fig. 138.—Curves illustrating the Influence of the Size and the Shape of the Lamp Filament on the resultant Illumination.

The presence or absence of glare may be quite independent of the size or power of the light source. Thus a bare 100-watt lamp in a double conical reflector of the type frequently used may, owing to the fact that the whole of the lamp filament is exposed and that the height at which such units are fixed is usually much too low, appear much more glaring than a light source the intensity of which is very much greater, but which is enclosed in a suitable lantern and fixed at a satisfactory height, and it is, in this connection, interesting to note that merely enclosing the light source in a clear-glass globe reduces both glare and irradiation to a marked extent.

Motorists in particular find it impossible to drive in comfort along a thoroughfare illuminated by such bare lamps, and any one who has not actually made the experiment will find it impossible to realize the difficulty of driving under such conditions.

Asymmetrical reflectors, or refractors, designed to project the light along the length of the street are, as might be expected, always more glaring than those of the symmetrical type, in which the light distribution can be designated by a solid of revolution about a vertical axis, and the plan of which at any height is, in consequence, always a circle. This is due to the fact that asymmetrical fittings concentrate the light flux into two or, in the four-way type, four comparatively narrow beams, the intensity of which at certain angles must of necessity be greater than that of fittings of equivalent power having a symmetrical distribution, and this naturally results in increased glare. Furthermore, asymmetrical fittings are, as a general rule, designed for a greater spacing-height ratio than those of the symmetrical type, with the result that if the light rays of maximum intensity are to reach the plane of reference at the mid-span position they must perforce be projected at a greater angle from the vertical, and an angle which is therefore more objectionable from the point of view of glare.

The complexity of the problem of the elimination, or reduction, of glare will be appreciated from the foregoing. It is, owing to conditions beyond the control of the lighting engineer, rarely possible to evolve a completely satisfactory solution, and the object to be sought is, therefore, the securing of the most effective compromise between, upon the one hand, reasonable economy in the matter of the number of lanterns used for a given length, and, upon the other, reasonable freedom from objectionable glare.

The term ‘objectionable glare’ is used advisedly, because experience has proved that exactly what constitutes glare is very largely a matter of personal taste. Absolutely glareless lighting is rarely looked upon as entirely satisfactory, and is usually considered to lack vitality. Again, what one individual will describe as glaring another will consider delightful, and as the ultimate criterion of any public lighting will be its appreciation or otherwise by the public concerned, the possibility, not to say probability, of a marked variation in individual taste should by no means be ignored.

Although it is impossible to lay down rules for the prevention of glare which will prove effective under all conditions, there are certain points which should always receive attention. Clear bare lamps, especially if of the gas-filled type, should never in any circumstances be used. Lanterns having a symmetrical, but definitely lateral, distribution are to be preferred for the reasons already stated. The height at which the lanterns are fixed should be ample—if any doubt exists it is wiser to err on the high side. Finally, the spacing-height ratio should be carefully considered, as to place the angle of maximum candle-power at from 70 to 75 degrees from the vertical, instead of from 80 to 85 degrees, is one of the most important factors in the reduction of glare.

Testing of Installations.—Whilst it is now universally recognized that street-lighting installations can no longer be judged wholly by appearances, which, from the point of view of illumination, are apt to prove more than usually deceptive, the number of tests which ought properly to be taken in any given case, and the manner in which they should be made, still remain matters upon which opinions differ very considerably.

Many engineers incline to the view that the most satisfactory method is the measurement of the candle-power at a specified angle from the vertical, a requirement frequently found in more or less ancient specifications; whilst others consider the arithmetical mean of candle-power measurements at two angles, usually 20 degrees and 70 degrees from the vertical, a more correct indication of the efficiency of the installation as a whole.

Among the larger number who agree that the correct basis should be the measurement of the actual illumination, there remains disagreement as to whether such measurements as are necessary should be made upon the vertical or the horizontal plane, and if the latter, whether at ground-level or at some, and if so what, distance above ground-level. Again, those who have in the past agreed that a horizontal plane—say, for instance, 3 feet above ground-level—is preferable have been far from unanimous as to whether the minimum, the maximum, or the average intensity forms the most satisfactory criterion of the excellence or otherwise of the resultant illumination.

The rapid growth of the science of illumination during the post-war years, and, in particular, the widespread application of scientific methods to the lighting of public thoroughfares, has enabled the merits and demerits of these various methods of testing to be more fully explored, with the result that the number of those in favour of accepting the measurement of the minimum horizontal illumination at the mid-span position as the determining factor is steadily increasing, and many illuminating engineers are now of the opinion that if, and when, the standard specification for street lighting makes its appearance it will call for the application of this test.

The advantages of the horizontal plane are that, with light sources having normal distribution, if the illumination upon it is sufficient, that upon the other planes must necessarily be better; and that, as the illuminations received from all neighbouring lamps add themselves together and give one single quantity which may be measured by a single observation, the economy of time and saving of calculation are enormous.

Horizontal illumination also shows the combined illuminating effect of lamps in both directions, which no other measure accomplishes, and therefore leads to the determination of the total light flux upon the street, which is a valuable quantity in gauging street illumination.

In an ably reasoned article on this subject ('A New Criterion of Street-lighting Excellence,' L. B. W. Jolley, M.A. (Cantab.), M.I.E.E., and C. A. Morton, B.Sc., *Illuminating Engineer*, June 1925), recently published, and which should be studied in detail by all interested, the authors, after an exhaustive examination of the various available methods of testing, arrive at the conclusion that the most generally satisfactory and reliable comparative test is undoubtedly the measurement of the minimum horizontal mid-span illumination.

Assuming this to be the case, there remains to be determined the plane upon which the measurements are to be taken. Whilst from a purely theoretical standpoint there may be something to be said for the surface of the actual street or road, practical considerations render preferable the use of a higher level. Measurements have of necessity frequently to be made under conditions of traffic, and at seasons of the year, which make it impossible for the test surface to be placed on the ground with any degree of safety, quite apart from the fact that in certain and by no means uncommon circumstances it would, if so used, be quickly ruined by mud and dirt. In other cases the photometer itself is mounted upon a carriage, or trolley, in such manner as to preclude the possibility of taking measurements at ground-level.

For these reasons, and also for the sake of uniformity and ease of comparison, it is strongly recommended that measurements should always be made on a horizontal plane 3 feet above ground-level, a practice now becoming almost universal in both this country and America.

If an extraneous test surface is used, it should be carried upon a suitable tripod, and it will be found a convenience in working if this is provided with folding metal pieces, or even strings, attached to the respective legs in such manner that when the latter are spread apart the level of the test surface is exactly 3 feet above the ground. A self-aligning head, carrying the test surface, which automatically sets itself in a horizontal plane promotes rapid working. Where such is not available the test surface should be carefully and accurately levelled before any measurement is made, and for this purpose a small circular spirit-level of the type used on photographic cameras, and which can be laid on the centre of the test surface, will be found very useful. If in addition to the measurement of horizontal illumination other measurements are required, such as the measurement of illumination on an inclined or vertical plane, or the measurement of candle-power at specified angles, a more complicated tripod head fitted with appropriate movements, and scales, will be required.

The photometer used should be an instrument capable of giving results of a high order of accuracy, and of satisfactorily withstanding continual usage in the open. Many of those available are quite unsuitable for the testing of street lighting, and certain types are worse than useless.

A portable photometer for the measurement of street illumination should be capable of measuring very low intensities, and should be provided with means for the accurate adjustment of the illumination at the comparative screen.

A really reliable voltmeter or ammeter is essential. The type of instrument frequently fitted is practically useless, not so much from the point of view of the unsuitability of the actual meter, as because the scale is insufficiently finely divided for serious work.

The source of light in present-day portable photometers is a small incandescent electric lamp, usually operating at either 2 or 4 volts, and the current for which is furnished by two or more dry cells or an appropriate accumulator. It was shown, when considering lamps, that a small change in the terminal voltage resulted in a considerably greater change in the candle-power emitted, and as, if accurate results are to be obtained, the light output of the photometer lamp must remain substantially constant, the necessity for extremely close regulation of the applied voltage, or current, and hence an accurate and very finely divided scale on the voltmeter or ammeter provided, will be apparent.

In the well-known Macbeth illuminometer, for instance, a 2-volt lamp taking a current of approximately 0·235 ampere is used.

Within the limits of plus or minus 1 per cent., the candle-power varies 5 per cent. for a 1 per cent. change in voltage, or 10 per cent. for a 1 per cent. change in current, and this may be taken as typical of the performance of such lamps as a class. If, therefore, it is desired that the candle-power of such a photometer lamp shall be correct within even 5 per cent., the voltage at its terminals must remain constant within at least 1 per cent., or the current passing through it within 0·5 per cent.

As 1 per cent. of 2 volts represents only 20 *milli-volts*, and 0·5 per cent. of 0·235 of an ampere only 1·175 *milli-amperes*, the absolute necessity for a meter provided with a scale upon which such minute variations can be easily and accurately read, under the by no means ideal conditions experienced in outdoor work, and the hopelessness of the ordinary voltmeter indicating from 0 to 6 volts, or ammeter indicating from 0 to 2 amperes, hardly requires emphasis. Other things being equal, it is advisable, for the reason already set forth, when purchasing a photometer to select a pattern in which the current is controlled and measured rather than the voltage.

Given a suitable photometer, and assuming that the measurement of the mid-span illumination on a horizontal plane 3 feet above the ground-level is taken as the criterion of excellence, or basis of comparison, measurements should be made in a number of adjacent spans, say ten or twelve, and where a drop in pressure is known to exist, or is suspected, measurements should always be made in those spans where the pressure is lowest. The current or voltage of the photometer lamp should be checked before every measurement, and a number of readings, say three or five, made at each point, the mean of which should represent the measured illumination at the spot in question.

When it is desired to ascertain the illumination between two standards, for the purpose of, for instance, showing the results obtained in the form of an illumination curve, such as that given in Fig. 132, measurements, made in the manner previously described, should be taken at intervals of say 5 feet, commencing immediately beneath one lamp and terminating beneath the next. In order to guard against the possibility of selecting a span the lamps illuminating which are each operating at the upper or lower limit of candle-power, measurements should be made along two or more spans. If these repeat within close limits, all is well; but if the differences between the readings obtained in the respective spans are material, care should be taken to see that the lamps are of the correct wattage and voltage, and are operating satisfactorily, and that the glassware is clean. The voltage should always be taken at each lamp at the time the measurements are made, in order that if it be too high, or too low, the necessary correction in the illumination readings may be made. If the ground falls away from any lamp to a marked extent, such as might happen in the case of standards fixed along a steep incline, the readings obtained may not represent correctly the true illumination at the point in question, and in such case will require modification to compensate for the difference in level.

Maintenance.—It is obvious that the initial efficiency of a street-lighting installation cannot be retained unless a systematic maintenance schedule is adopted and rigidly enforced. Lanterns and glassware should be carefully cleaned at appropriate regular intervals, and all lamps regularly renewed at the expiration of their normal life of 1,000 hours of burning. The amount of cleaning necessary—that is to say, the maximum interval of time which can be allowed to elapse between one cleaning and the next—will naturally vary according to local atmospheric and other conditions. It can, however, readily be established for any particular installation, and having once been determined should not be exceeded. In many of the best installations the authorities responsible take considerable pride in the appearance of the fittings, and clean at sufficiently frequent intervals to maintain a good daylight appearance, with results which are all to the good from the point of view of the resultant illumination, and which reflect the greatest credit upon all concerned.

The permissible interval between cleanings is sometimes determined by noting the time taken for the minimum mid-span illumination to fall by a predetermined amount, say 20 or 25 per cent. If this method is adopted, care should be taken to make all measurements with the same lamp in use and at the same spot, and carefully to note the voltage each time a measurement is made, in order that if this varies, as it probably will, the necessary correction may be applied.

One of the most important factors in the maintenance of any installation of street lighting is the lighting and extinguishing of the various lamps. This has already been touched upon in connection with ‘switching,’ but requires further consideration in this connection. If the switching is performed by hand, and all the lamps are required to be ‘on’ by lighting-up time and must remain on until after the scheduled time for switching ‘off,’ then in an installation of any magnitude either the number of men detailed for this work must be such as to enable the whole of the area to be covered sufficiently quickly, or the hours of burning, and consequently the amount of electrical energy consumed, will be considerably increased and the annual cost proportionately augmented. This factor is of course most important where large numbers of high-wattage lamps are used, and it is in such cases that the disadvantage of hand switching is most pronounced.

If, on the other hand, the switching is performed automatically, by the employment of time switches, the question of ‘scouting’ will have to be considered. When the lamps are switched on and off by hand any defect should be, and usually is, noticed and reported immediately by the individual in whose area it occurs. If not rectified during the following day, it would again be noticed and reported on the following night, and if such reports are dealt with daily, as they should be, they enable the installation to be more easily maintained in a highly efficient condition.

In many cases it is possible to arrange for the police to take over the work of reporting any defects in the lighting equipment, and, where it can be entered into, such an arrangement is most desirable from every point of view, as, apart from its relieving the lighting authority of the work, it enables any defect to be notified immediately, in some cases within a few minutes of the fault developing, which is not possible by any other method short of a continuous patrol.

Where this cannot be done and the switching ‘on’ and ‘off’ is performed automatically, it is essential, from the point of view of satisfactory street lighting, for the whole of the area to be patrolled either nightly or at such less frequent intervals as the decreased importance of the installation may warrant.

Whatever the method of ‘scouting’ may be, the fact that, in the absence of the light from the lamp which it carries, the standard supporting a dark lamp may in itself constitute a dangerous obstruction must not be overlooked. Central standards are especially dangerous in this respect, unless the span is short enough to enable the lamps which are burning to provide a sufficiently high illumination to render easily visible both the column on which the lamp is defective and the curb of the island upon which it stands, or unless they are provided with pilot lamps, the illumination from which is sufficient for this purpose, operating on a separate circuit, as shown on certain of the examples illustrated in Fig. 110.

Whole and Half Night Lighting.—Although not essentially connected with the question of maintenance, the desirability or otherwise of the use of all-night or half-night lighting can conveniently be considered at this stage.

In towns of any importance the whole of the lamps should burn all night, and the progressive lighting authorities of many of our big cities are already working on these lines. The practice adopted in certain districts of extinguishing alternate lamps at midnight, or at an early hour of the morning, undoubtedly increases the risk of accident by diminishing and rendering more uneven the available illumination, and unless each standard carries two or more separate lanterns may constitute a definite danger.

Such procedure is least objectionable where overhead suspensions or wall brackets are used, and, if adopted in those cases employing standards for supporting the lanterns, pilot lights operating on a separate circuit and arranged to burn all night should always be provided.

Conversion of Gas Lamps.—A phase of street lighting which is receiving considerable attention at the present time arises from the increasing replacement of gas by electricity for the illumination of secondary streets. Large numbers of ordinary gas lamps have been so successfully adapted for the reception of gas-filled electric lamps that in certain areas gas has practically become a thing of the past as far as the public lighting is concerned. The number of such lamps still to be dealt with throughout the country is, however, so great that it will undoubtedly be of interest to consider the means by which their conversion can be effected satisfactorily and economically.

Where the expense of new lanterns does not constitute an insuperable obstacle, the existing lanterns can be removed and the standards fitted with extension brackets of the type shown in Fig. 139. By this means the height can very easily be increased from 3 to 4 feet, which is usually a distinct advantage. The spigot cap is arranged to fit over the spigot on the existing lamp-post, to which it is secured by three set screws. As the cast-iron posts carrying gas lamps are not usually provided with a door in the base, either a time switch as shown, or a hand-operated switch of circular type is incorporated with, or fixed immediately above, the spigot cap. The swan-neck bracket arm which carries the lantern, and in which are accommodated the necessary insulated conductors, can be of any suitable dimensions, and can be ornamented or enriched in such manner as to enable the fitting, as a whole, to harmonize with the character of the post which it surmounts. The 'Wembley' lantern shown takes a 300-watt gas-filled lamp, and the complete fitting is one which has been extensively utilized for conversions of this description.

In those cases where, owing possibly to the large number of points to be dealt with, it is desired to make use of the existing lanterns, the latter can usually be converted, if their condition is sufficiently serviceable, in the manner illustrated in Fig. 140, which shows a square glazed lantern of a type very largely used for gas lighting. The existing frog carrying the lantern and the actual gas burner are removed. A new spigot cap, switch-box, and frog are provided, to which the existing lantern is attached, and a small fitting incorporating a lamp-holder of appropriate size and the single-piece prismatic glass refractor shown is accommodated in the upper portion.

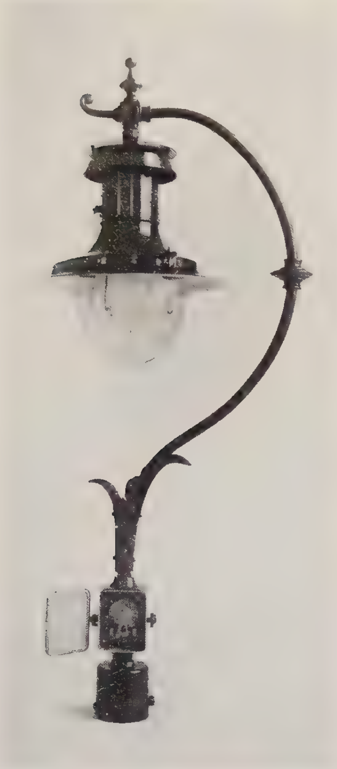

Fig. 139.—Extension Bracket and Lantern for use on Gas Post.

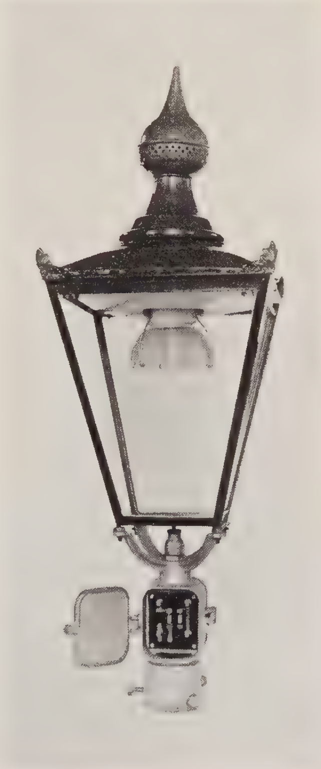

Fig. 140.—Conversion Fitting for Gas Lamp.

The lead-covered twin conductor passes from the switch-box up one of the corner bars of the lantern to the lamp-holder, and can just be distinguished in the illustration passing along the inside bar on the left-hand side. The lanterns, one of which is shown in Fig. 140, were each fitted with a 100-watt gas-filled lamp. In Figs. 139 and 140 the switch-box shown has two compartments (one on each side), each provided with a door and containing respectively a time switch and fuses on each pole.

A still less costly conversion is shown in Fig. 141, in which are reproduced photographs of a hexagonal glazed lantern showing its appearance before and after alteration. As originally used, the lanterns were equipped with a double-inverted gas burner, fitted with superheater, controlled by a governor, and consuming a total of 7 cubic feet of gas per hour at a main pressure of 2·5 inches of water. As converted, each lantern was fitted with two 60-watt, clear, gas-filled electric lamps at 4-inch centres.

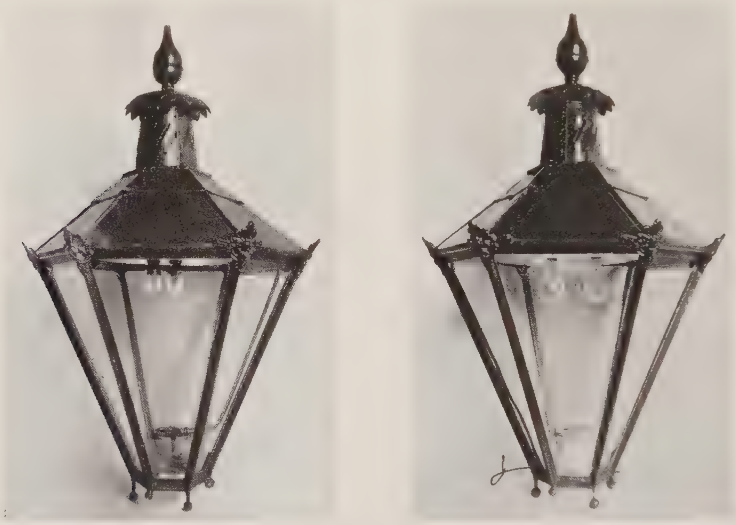

Fig. 141.—Gas Lamp before and after Conversion to Electricity.

It is usually possible to obtain from such converted gas lamps results of so satisfactory a nature as to render their alteration well worth carrying out, a particularly striking feature being the increased illumination at the mid-span position obtained by the use of the refractor shown in Fig. 140.

The type of emission likely to be obtained from such converted lanterns may be gathered from an inspection of the polar curves shown in Figs. 142 and 143. Fig. 142 shows the light emission in a vertical plane given by the lantern illustrated in Fig. 140, when equipped with a 100-watt, wreath-filament, clear, ‘Osram’ gas-filled lamp, the lamp being new and the glass panes clean.

As the lanterns illustrated in Fig. 141 each contain two light sources, spaced 4 inches apart along a common centre line, polar curves were taken in a plane of symmetry (a plane passing through both light sources), and also in a plane at an angle of 45 degrees to such plane.

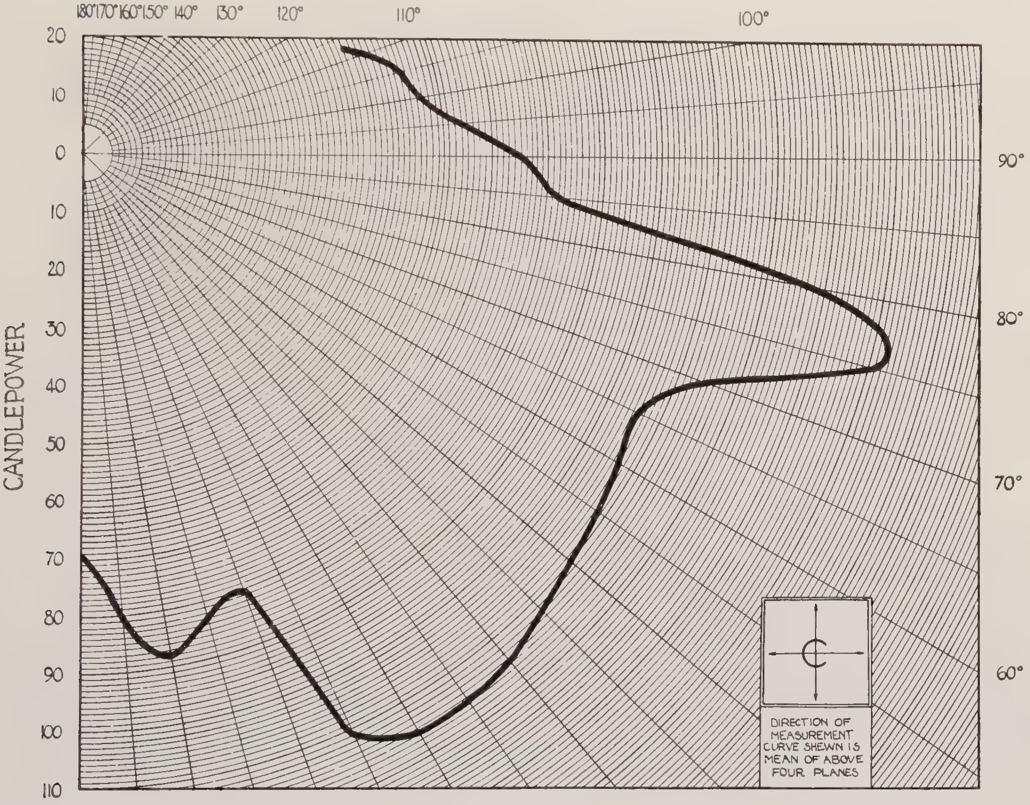

Fig. 142.—Polar Curve showing Light Emission in a Vertical Plane given by the Lantern illustrated in Fig. 140.

In Fig. 143 curves A and B show the light emission from a lantern equipped with two 60-watt, wreath-filament, clear, ‘Osram’ gas-filled lamps, and curves C and D that from a similar lantern containing two inverted gas mantles, with superheater and governor, and consuming a total of 7 cubic feet of gas per hour at a main pressure of 2·5 inches of water. Curves A and C show the emission in a vertical plane passing through both light sources, and curves B and D that in a vertical plane at an angle of 45 degrees

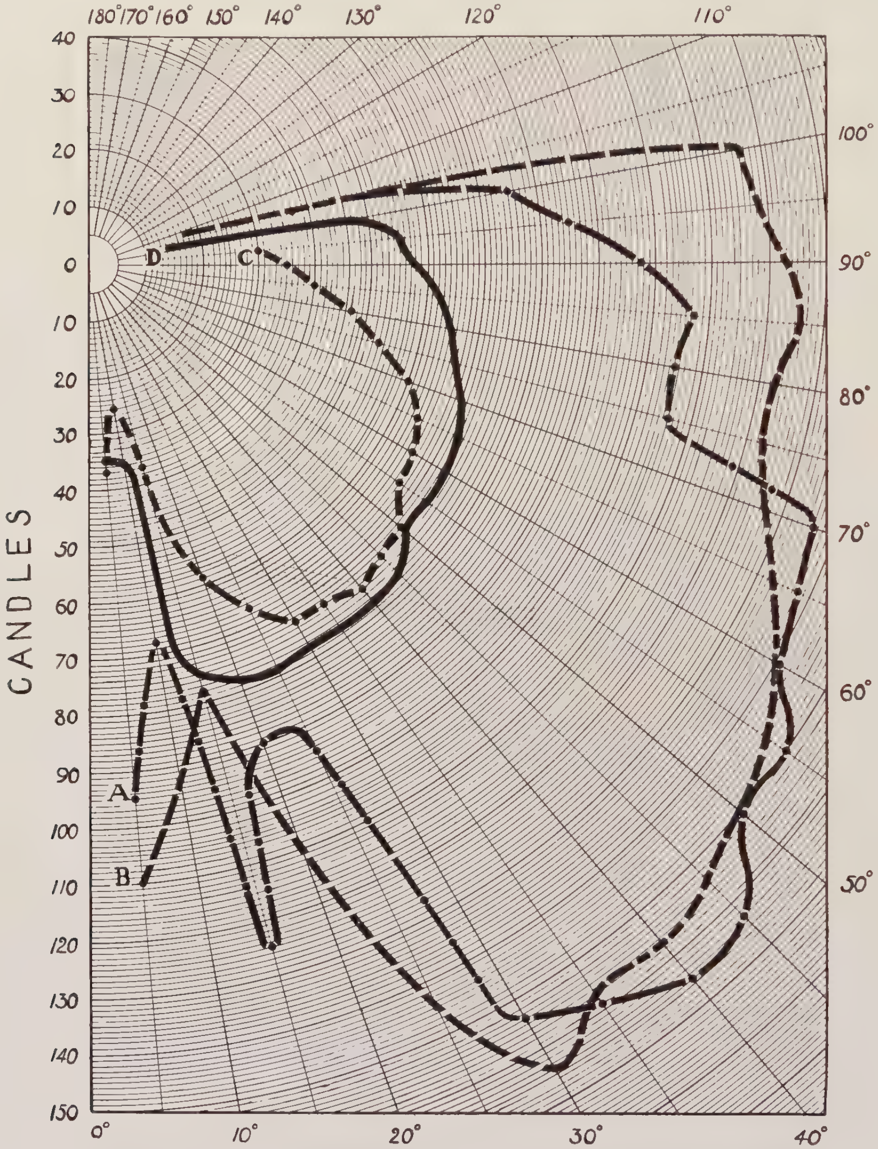

Fig. 143.—Polar Curves showing Light Emission in a Vertical Plane given by the Lantern illustrated in Fig. 141.

thereto. It is interesting to compare the relative intensities angle by angle.

Signal Lanterns and Illuminated Road Signs.—The tremendous increase in the development of motor traffic, and, in particular, in the number of commercial vehicles travelling by night, has led to the introduction, and use at dangerous or difficult points, of signal lanterns bearing warning devices visible from all sides, and equally conspicuous by day or night. Interest is also being exhibited in the more extensive use of road signs for the regulation and direction of traffic, such as ‘ white lines,’ arrows, etc., embedded in the surface of the road, and which, in addition to being clearly visible by day, can be rendered luminous at night.

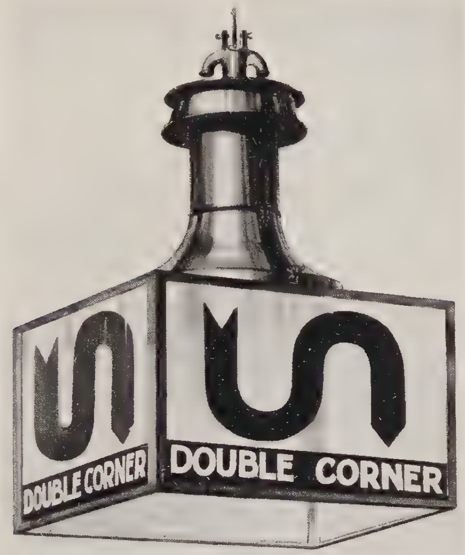

Fig. 144.—‘ Wembley ’ Lantern fitted with Illuminated Signs for Direction of Traffic.

The comparatively few such lanterns required in an average installation of street lighting can be fitted with appropriate signs in the manner shown in Fig. 144 without materially impairing their general usefulness, or adversely affecting the resultant illumination to an appreciable extent. The four opal-glass panels shown can, of course, bear any of the designs recommended and adopted by the Ministry of Transport for the indication of speed limits, or the proximity of dangerous hills, cross roads, schools, etc., or any special route indication which may be required.

The ‘ white line ’ illustrated in Fig. 145, in use in the outskirts of London, possesses the advantage of being as visible, and therefore as valuable, at night-time as during the hours of daylight.

The frame of wrought iron, about 3½ inches wide by 5 inches deep, is formed in three sections, has a total length of about 30 feet, and is embedded in the roadway as shown. In the top of the frame are inserted pieces of laminated white marble and prism glass, of suitable thickness, arranged alternately. A recess below the glazing accommodates a number of 40-watt lamps which, when in operation, produce an apparently continuous white line visible to motorists at a distance of 200 yards.

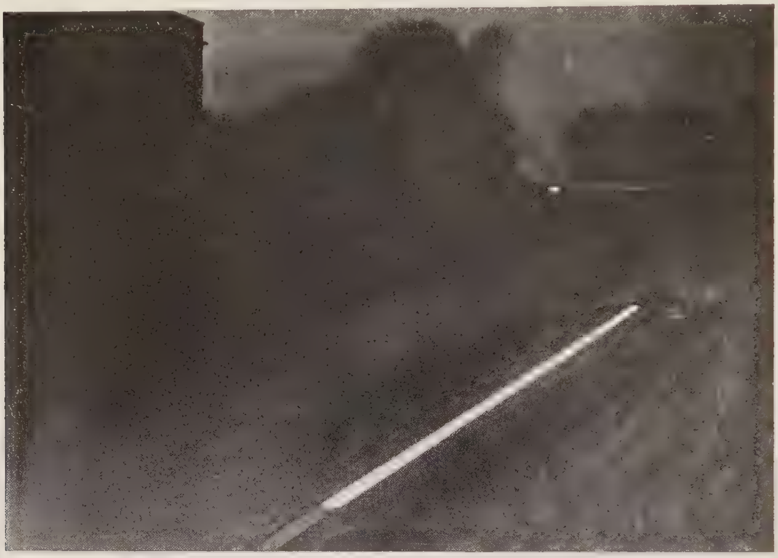

Fig. 145.—'White Line' illuminated by Electric Lamps.

The lamps are protected from mechanical shock caused by the passage of heavy traffic, are supplied with current from the supply mains, and are switched on at dusk and extinguished at daybreak by an automatic time switch. Although the example illustrated consists of a single straight line, curved lines, arrows, or any other device can equally well be constructed and illuminated in the same way.

CHAPTER VI

MOTOR-CAR HEADLIGHT ILLUMINATION

The Parabola—Construction of Parabola—Parallel Beam from Parabolic Reflector—Beams with Light Source in front of and behind Focal Point—Method of determining Focus of Light Source—The 'Graves' Automobile Lamp—Experiments carried out with Ordinary and Anti-Dazzle Lamps—Complete Wiring Diagram for Motor Car.

A MOTOR-CAR may be compared with a miniature central station; it contains a complete generating unit, accumulators, a motor for starting, and, for its size, an extensive lighting installation. Of the different types of units which go to make up the complete installation there is none more important than the headlighting unit. The unit operates by means of a lamp in a parabolic reflector; it is the characteristics of the reflector which enable light from a certain focal point to be directed in a beam of a certain shape in the desired direction. The 'efficiency' of the beam depends upon the position of the lamp in the reflector, and to thoroughly understand this it is necessary to have a comprehensive knowledge of the construction of a parabola.

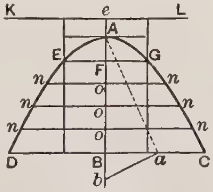

FIG. 146.

A parabola DAC (Fig. 146) is the contour of the ideal motor-car headlight. The contour is such that every point in the curve is equally distant from the directrix KL and the focus F. The focus lies in the axis AB drawn from the vertex or head of the curve A, so as to divide the figure into two equal parts. The vertex A is equidistant from the directrix, and the focus, or $Ae = AF$. Any straight line parallel to the axis is a diameter.

A straight line, as EG or DC, drawn across the figure at right angles to the axis is a double ordinate, and either half of it is, of course, an ordinate. The ordinate to the axis EFG, drawn through the focus, is termed the perimeter of the axis. A segment of the axis, calculated from the vertex, is an abscissa of the axis, and it is an abscissa of the ordinate drawn from the base of the abscissa. Thus, AB is an abscissa of the ordinate BC. Abscissæ of a parabola are as the squares of their ordinates.

A parabola can be constructed, when an abscissa and its ordinate are known, by bisecting BC at a, and drawing Aa and then *ab* perpendicular to it, meeting the axis at *b*. Then set off A*e*, AF, each equal to B*b*, and draw K*e*L perpendicular to the axis. Then KL is the directrix and F is the focus. Through F and any number of points *o*, *o*, etc., in the axis, draw double ordinates *non*, etc., and from the centre F, with the radii F*e*, *oe*, etc., cut the respective ordinates at E, G, *n*, *n*, etc. The curve may then be traced through these points as shown.

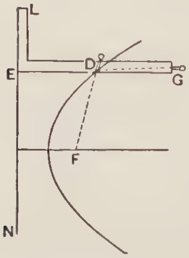

Fig. 147.

It can be constructed by another method (Fig. 147) in which is used a square and a cord. This method is as follows:—Place a straight-edge to the directrix EN, and apply to it a square LEG. Fasten to the G one end of a thread or cord equal in length to the edge EG, and attach the other end to the focus F; slide the square along the straight-edge, holding the cord taut against the edge of the square by a pencil D, by which the curve is described.

When the height and base are given, the parabola can be drawn by the method illustrated in Fig. 148. Here let AB be the given axis, and CD a double ordinate or base; the parabola has its vertex at A. Through A draw EF parallel to CD, and through C and D draw CE and DF parallel to the axis. Divide BC and BD into any number of equal parts, say five, at *a*, *b*, etc., and divide CE and DF into the same number of parts. Through the points *a*, *b*, *c*, *d* in the base CD on each side of the axis draw perpendiculars, and through *a*, *b*, *c*, *d* in CE and DF draw lines to the vertex A, cutting the perpendiculars at *e*, *f*, *g*, *h*. These are points in the parabola, and the curve may be traced as shown, passing through them.

The light from motor-car headlights must serve two purposes. First, the light must be thrown far enough ahead with sufficient illumination to distinguish objects in time to change the direction and speed of the machine according to the object, whether it be a vehicle or a rut, in the way; second, there must be sufficient illumination on the road in front and to the side of the car, so that the driver can see what he is turning into on changing his direction. The first point is most generally considered.

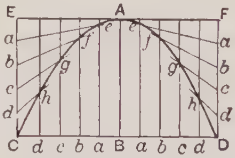

Fig. 148.

The chief essential, then, is to obtain a beam which is capable of delivering a maximum amount of light from a given source in front of the car. A parabolic reflector meets this requirement owing to the fact that maximum light rays from the lamp are collected and redirected ahead; the extent to which the rays are redirected, however, depends upon the position of the lamp in the reflector.

Let us assume that we have a theoretical light source, a source upon which all the laws of light are based; that is, a source in which all the rays of light emanate from a single point. If we place this source at the focus of a true parabolic reflector, the whole of the rays which strike the reflector will be redirected parallel to the axis of the reflector. This produces a cylinder of light rays whose diameter is that of the reflector opening; this is illustrated in Fig. 149. This cylinder will consist of a definite quantity of light which is expressed in units of quantity, *i.e.* lumens. If this light falls on a wall 25 feet distant the quantity of illumination will be of a certain value; if the wall were 250 feet away, or 2,500 feet for that matter, assuming that there was no absorption due to dust or moisture, the quantity of illumination would be the same.

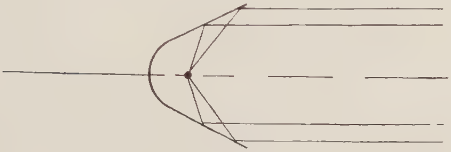

FIG. 149.

From this it will be seen that the light from a truly focussed light source in a parabolic reflector does not follow the law of inverse squares which states: 'The illumination received by a plane is inversely proportional to the square of the distance of the plane from the source.' Since light travels in straight lines unless reflected or refracted, it is evident that every ray of light coming from a point source L (Fig. 150) must take a direction different from every other ray of light. It is on this fact that the law of inverse squares depends.

In a cylinder of light from a parabolic reflector the whole of the rays are parallel; that is, they have the same direction. This is exactly the opposite condition of the basis of the inverse square law. The law is therefore not applicable in this case. This makes it impossible to say that this beam has a certain candle-power, inasmuch as candle-power is not measured directly but is computed in accordance with the inverse square law from a determination of the illumination at a given distance.

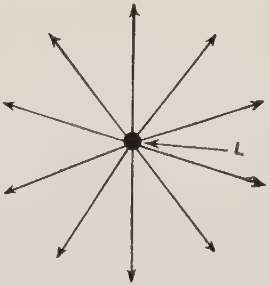

FIG. 150.

Up to the moment we have only been considering theoretical conditions. In practice we can obtain a reflector which has a true parabolic curve, but the theoretical light source is an impossibility. It is to our advantage that it is so, because the beam of light with merely the diameter of the reflector would not illuminate enough surface on the road to be of any value.

In the manufacture of motor-car lamps the filament is as small as it is possible to make it; in this way the light source approximates to the theoretical point source. A large portion of the filament, however, lies in front of, or behind, the focal point of the reflector. The light from this part of the filament does not take the parallel direction, but either diverges or converges according to whether it originates behind or in front of the focus. The amount of convergence or divergence increases with the distance from the focus from which the light comes.

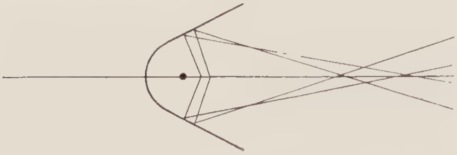
Fig. 151.

The beam of light actually obtained from a parabolic reflector consists, then, of light having three characteristic directions: first, that which originates at the focus of the reflector and takes a direction parallel to the axis (Fig. 149); second, that which originates in front of the focus and converges (Fig. 151) (the converging rays cross at some point in front of the reflector, and from that point are diverging); third, that which originates behind the focus and diverges (Fig. 152). In comparison with the total amount of light given by the reflector, that which falls within the first classification is comparatively small. There is light of still another characteristic direction which plays an important part in the roadway illumination near the machine, although it has little effect upon the projected beam of light. This is the light which comes directly from the lamp without striking the reflector (Fig. 153).

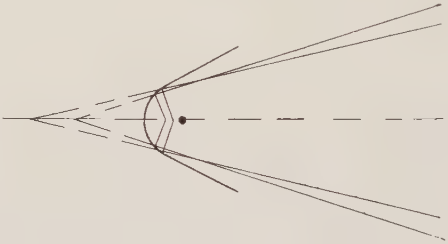
Fig. 152.

The result of these rays having four characteristic directions is a beam of light which is, on the whole, diverging. It would seem, then, that the inverse square law would apply to this beam, and that we could determine definitely the candle-power of the beam. It has been shown that this cannot be done for the parallel rays; they, however, form but a small part of the total beam. The illumination produced by the diverging rays does not strictly follow this law, inasmuch as the light apparently originates in a line and not in a point. This line is coincident with the axis of the reflector, and extends behind the reflector (Fig. 153). The same is true of the converging rays except that the line of origin is in front of the reflector

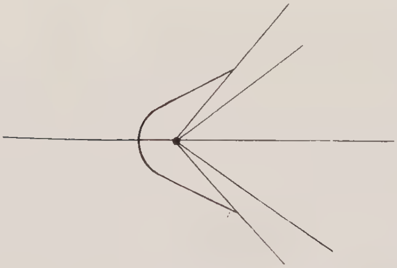
Fig. 153.

(Fig. 154). The illumination given by the direct rays from the lamp which do not strike the reflector follows the law exactly, but does not form an appreciable part of the beam. Considering only the diverging and converging rays, since these give practically the entire beam, we find that we have diverging light originating virtually along the axis of the reflector, extending both in front of and behind it.

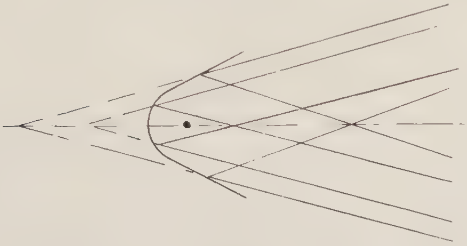

Fig. 154.

Candle-power values of a headlight must be computed by means of the inverse square law, from determinations of the illumination given at some distance. To do this we must know from what point to measure the distance at which the illumination readings are taken. This point is the *virtual* source of the light, and it lies somewhere on the axis. In all probability it lies at the focus of the reflector when the lamp is properly focussed, but it may be ahead of or behind this point if the light centre of the filament is ahead of or behind the focus. In any case, the point is near the focus of the reflector, and it is therefore sufficiently accurate to measure the distance from the focus of the reflector, provided the illumination readings are taken at a distance of 30 feet or more. This distance is great enough, as compared with the possible error in assuming the virtual source to be at the focus, to make the resultant error in candle-power calculations less than the inherent experimental errors.

Inasmuch as the beam apparently originates in a line and not in a point, it would appear that the inverse square law would not apply, and that, therefore, actual candle-power values could not be determined. Actual tests, however, do not point to this conclusion. Although tests such as we have carried out have not been entirely satisfactory from the standpoint of precision, because of the difficulties encountered in the photometry of the beam, we would say that the inverse square law does hold for the beam with at least as great accuracy as photometric measurements can be taken.

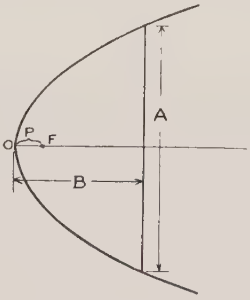

Fig. 155.

Regarding the exact focus of the parabolic reflector, this cannot be found by training a beam upon an object. It is always desirable to know where the focus is, so we describe herewith how, by means of two single measurements and a formula, it can be determined.

In Fig. 155, let A be a distance across the reflector perpendicular to its axis at any point, B the distance from this perpendicular line to the back end of the reflector, and P the focal length. The focal length, or the distance from the back of the reflector to the focus, is expressed by the formula :

$$P=\frac{A^2}{16B},$$

or

$$A^2=P\times 16B.$$

These measurements are so simple that it will be an easy matter for any one, with a small rule and a small stick or pencil, to determine the position of the focus.

One cannot think of motor-car headlights without immediately connecting them with dazzle and glare. A concentrated beam of light must produce glare, but the effect of glare depends upon the position from which the beam is viewed. It is possible to illuminate well a road and yet for glare not to be manifest to a person standing immediately in front of the beam. This can only be possible, however, through alterations on the reflector unit. The latest development in this direction is the introduction of the ‘ Graves ’ lamp (Fig. 156).

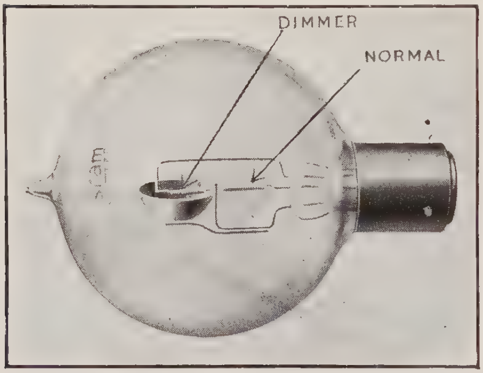

Fig. 156.—The ‘Graves’ Automobile Lamp.

This lamp has two filaments, located one immediately behind the other but in the same plane. The rear filament is in focus, but the other is shaded by a small semicircular metal cup fitted with the open side facing upwards. When the rear filament is in use the headlamps project the full normal driving light. When it is desired to ‘ dim,’ that is, on the approach of a vehicle, a throw-over switch is actuated and the forward filament is brought into operation. In this way the upward rays of light are effectively cut off.

In Figs. 157 and 158 the result of tests carried out with the ordinary and anti-dazzle filaments are shown respectively ; it would be difficult to determine anything more convincing than the results shown. The tests were carried out to demonstrate the difference in the shape of the beam projected from a motor-car head-lamp with the ordinary filaments and the anti-dazzle filament of the ‘ Graves ’ lamp.

In the tests one head-lamp was used, and this was fixed at a distance of 14 feet from a screen upon which the light was projected. Fig. 157 illustrates the beam from the anti-dazzle filament ; the line of demarcation is clearly shown. At further distances the beam dispersion is greater, and from what has already been written concerning beam-spread it will be seen that at the greater distances the space above the beam proper becomes illuminated by subdued light of low intensity, so that the cut-off is not too severe.

The shape of the beam-spread from the ordinary filament is illustrated in Fig. 158; this gives one an excellent idea of the glare which is experienced from motor-car headlights under ordinary conditions. The light in the upper portion of the beam is quite as intense as that in the lower portion.

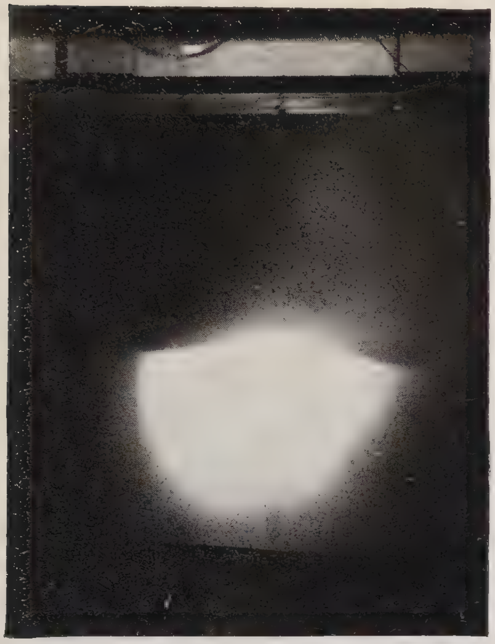

Fig. 157.—Beam of 'Graves' Automobile Lamp.

Fig. 158.—Beam of Ordinary Lamp.

The results of two further practical tests are illustrated in Figs. 159 and 160; these tests were carried out in a country road near Bickley, Kent. In Fig. 159 a pedestrian is seen under the light produced from the head-lamps of a motor equipped with ordinary filaments. Glare is distinctly observable to both driver and pedestrian, and, since the latter was dressed in white, it was only with difficulty that the driver could perceive her. In Fig. 160 the ordinary filaments have been replaced by the anti-dazzle filaments described. Here the figure is clearly discernible, and the upper portion is in semi-darkness. The beam-spread in both illustrations should be noted, because, with the anti-dazzle filaments, hedges and ditches are clearly illuminated, thus making it easier for pedestrians to cross the road.

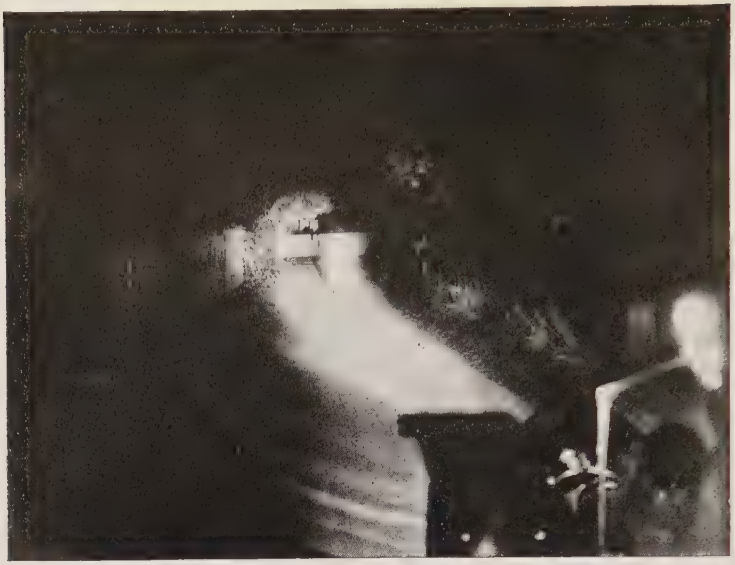

Fig. 159.—Illumination from Ordinary Lamp.

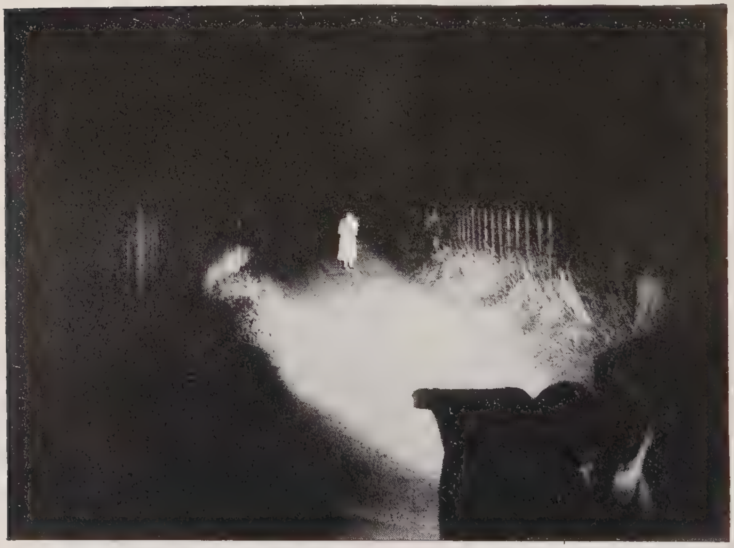

Fig. 160.—Illumination from 'Graves' Lamp.

Throughout these tests foot-candle readings were taken at various distances with both types of filaments in use. With the ordinary filament, as will be seen in Fig. 159, a large quantity of light is wasted on the house at the end of the lane and upon the tree-tops. It was also found, from readings taken near by, that a considerable proportion of the light was generally wasted. With the anti-dazzle filaments, it was proved that, although the length of the beam was decreased, the intensity of light was higher.

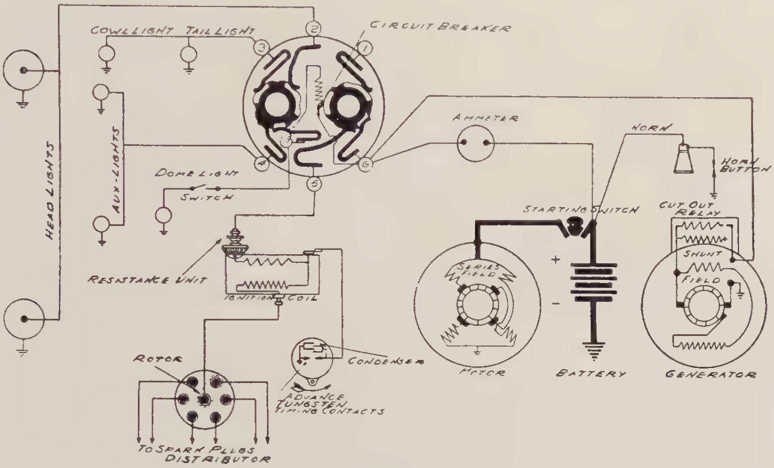

Fig. 161.

A complete diagram of connections showing positions of lighting units and their control is illustrated in Fig. 161.

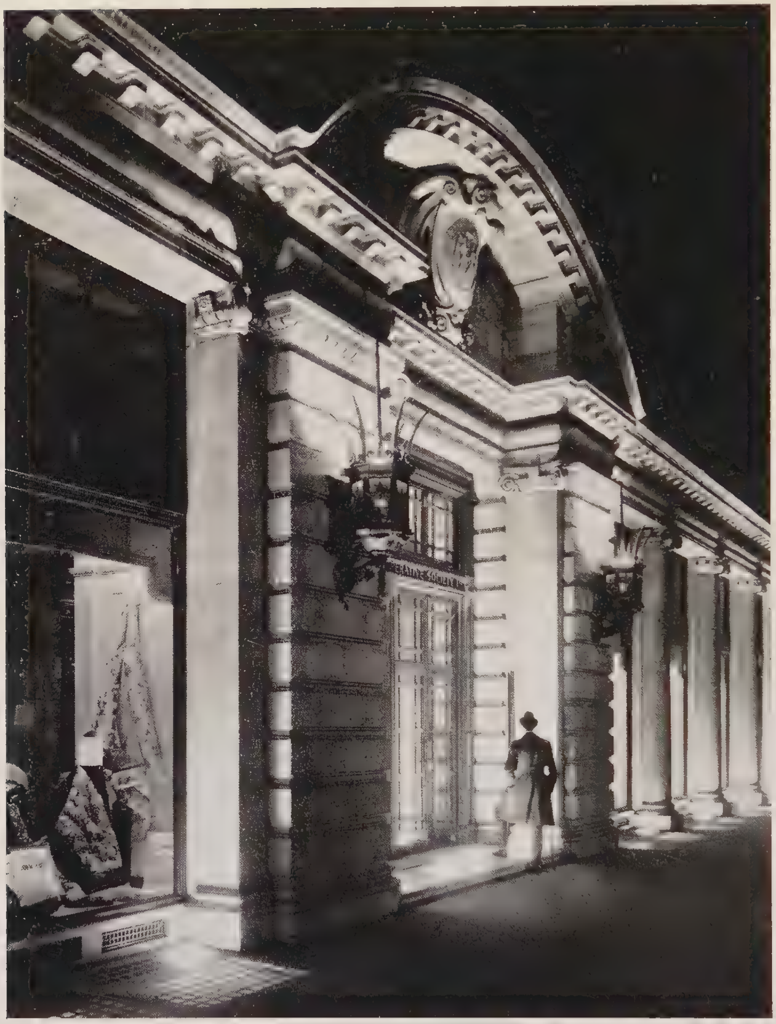

Fig. 162.—An Unique Installation. The Frontage is illuminated by Floodlights fixed below the pavement and by others concealed in the top of the Ornamental Lanterns shown.

CHAPTER VII

FLOODLIGHTING

Introduction—Applications—Choice of Equipment—Intensity of Illumination required—Covering Power of Floodlights—Angle of Beam—Spill-light and Overlap—Beam Efficiency—Lamps—Influence of Size and Shape of Lamp Filament—Use of Colour—Maintenance—Calculation of Requirements.

Introduction.—Floodlighting, which, as the name implies, involves the flooding with light of an object or area, is, contrary to the general belief, by no means a new science, and the many references to it as a totally new phase of illuminating engineering are an injustice to the development of the high-power searchlights so extensively used for naval and military purposes. Whenever a battleship directs her searchlights on to a sister ship, an opposing vessel, an airship, a seaplane, a fort, or the entrance to a dockyard, she is as surely *floodlighting* the object illuminated as is the illuminating engineer floodlighting a structure or statue in the midst of the metropolis. The difference is solely one of equipment ; in the one case a small number of powerful, long-range projectors are employed, while in the other the number is greater, the range shorter, and the power per unit materially less. A typical illustration of this type of floodlighting forms the subject of one of the well-known series of ‘ Black and White ’ posters. The conception is excellent, and the example (Fig. 163) bears striking, if unintentional, testimony to the value of light in advertising.

The employment of floodlighting produced by such means is, however, extremely restricted, owing to the fact that its creation necessitates the use of high-power arc lamps in complicated and costly projectors of considerable size and requiring skilled attention at frequent intervals.

The latest and in many respects the outstanding example of floodlighting on these lines is the remarkable illumination of the world’s most famous waterfalls—Niagara—shown in the photographs reproduced in Figs. 164, 165, and 166. The sheer majesty and beauty of the spectacle of these stupendous cataracts, with their aggregate flow of over 15,000,000 cubic feet of water per minute, bathed in and rendered luminous by beams of light projected by batteries of 36-inch arc searchlights, is something which defies description and must be seen to be appreciated.

The renaissance of floodlighting coincided with the advent of the high-power gas-filled lamp, and its future is assured. The high efficiency of this, the latest and, in many respects, the best of our modern light sources, its small size, the varied forms in which it is available, and its ability to burn for long periods without attention, have enabled the illuminating engineer to design comparatively small but withal exceedingly efficient projectors, and to fix them in positions which would not otherwise be possible.

Such projectors, or 'floodlights,' as they are now commonly called, provide the most effective and economical means of concentrating light on any desired subject. They possess the further advantage that they can be switched 'on' and 'off' by time switches fixed in positions remote from the projectors and capable of operating for long periods, thus doing away with the necessity for attention apart from occasional cleaning and re-lamping, and rendering possible the designing of installations which are, for all practical purposes, entirely automatic in their operation.

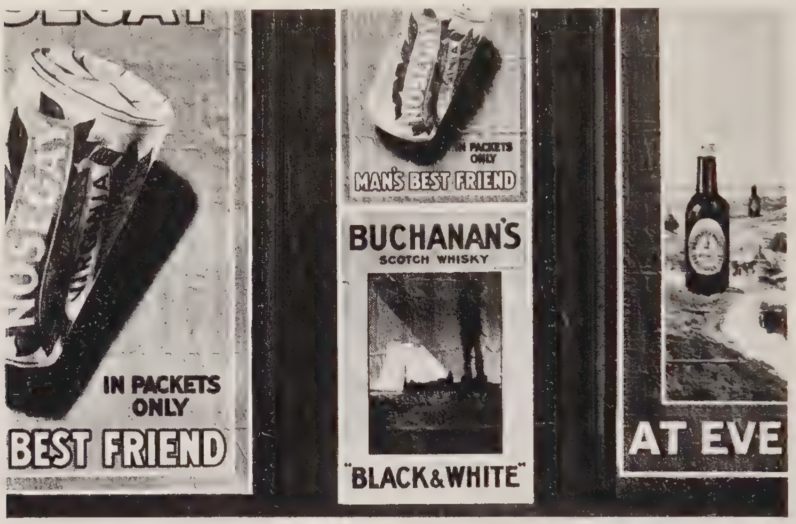

Fig. 163.—Example of Floodlighting in Advertising. The black gunboat is floodlighting the white sailing-ship.

That from the æsthetical standpoint the science of floodlighting has gained rather than lost by the change in equipment is apparent from an inspection of the examples illustrated. The appeal of a building such as that shown in the frontispiece, illuminated from every angle, bathed in soft radiance and viewed against the 'star-decked robe of night,' is irresistibly arresting. Not less beautiful, although of quite another type, is the example shown in Fig. 167, considered by many the finest of its kind in England.

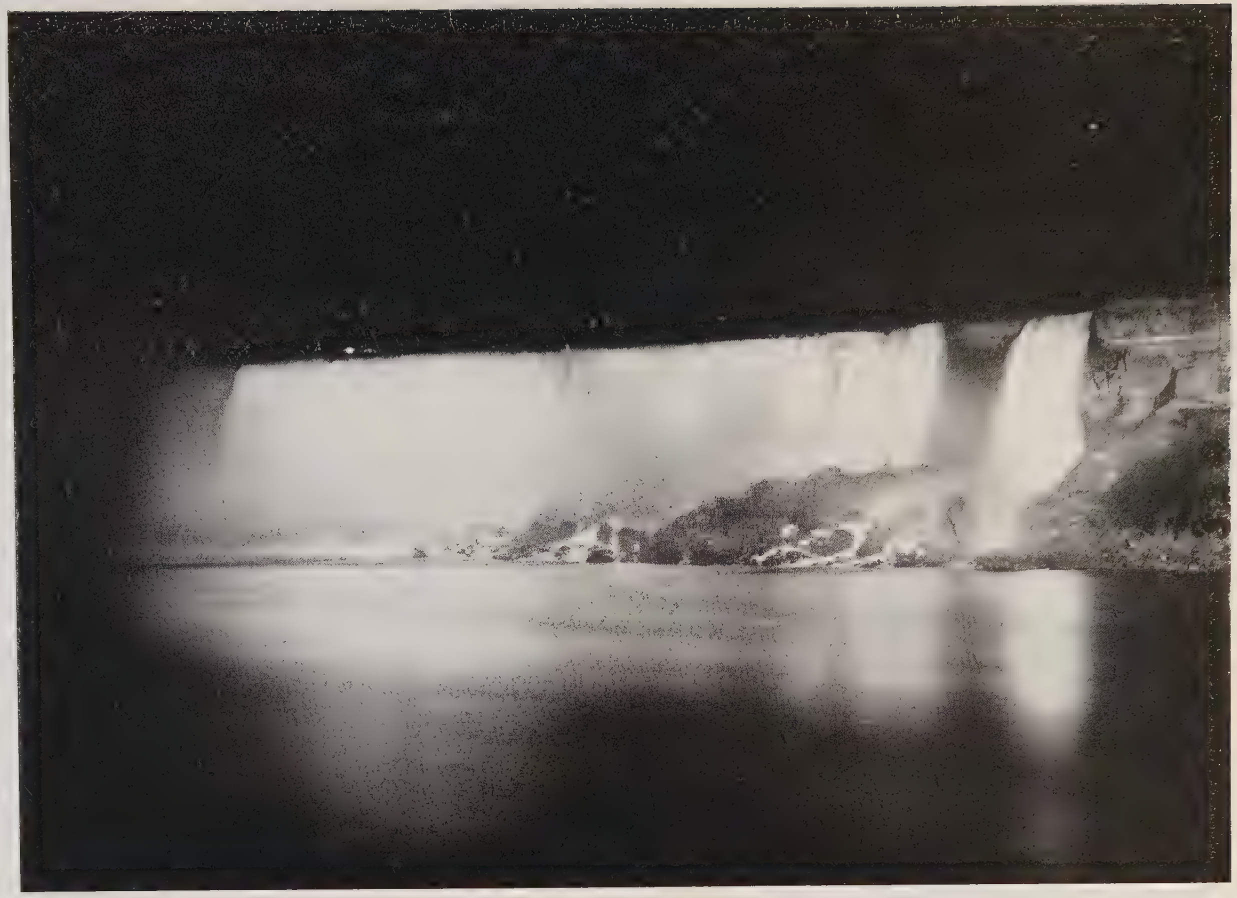

FIG. 164.—FLOODLIGHTING OF NIAGARA. AMERICAN AND 'BRIDAL VEIL' FALLS. (THE 'BRIDAL VEIL' FALL IS THE NARROW SEPARATE CATARACT ON THE RIGHT.)

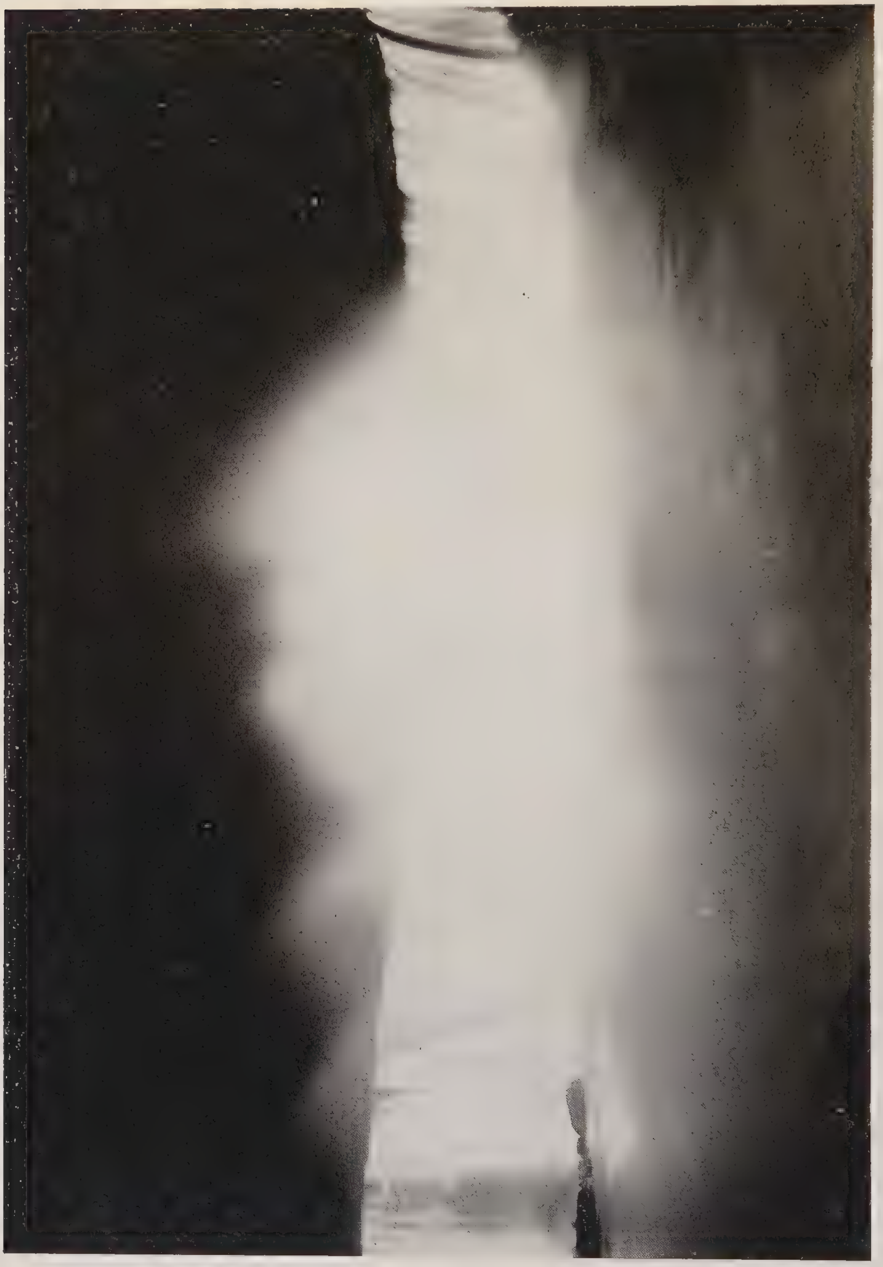

FIG. 165.—FLOODLIGHTING OF NIAGARA. A VAST CLOUD OF LUMINOUS SPRAY CAST UP BY THE HORSESHOE FALLS.

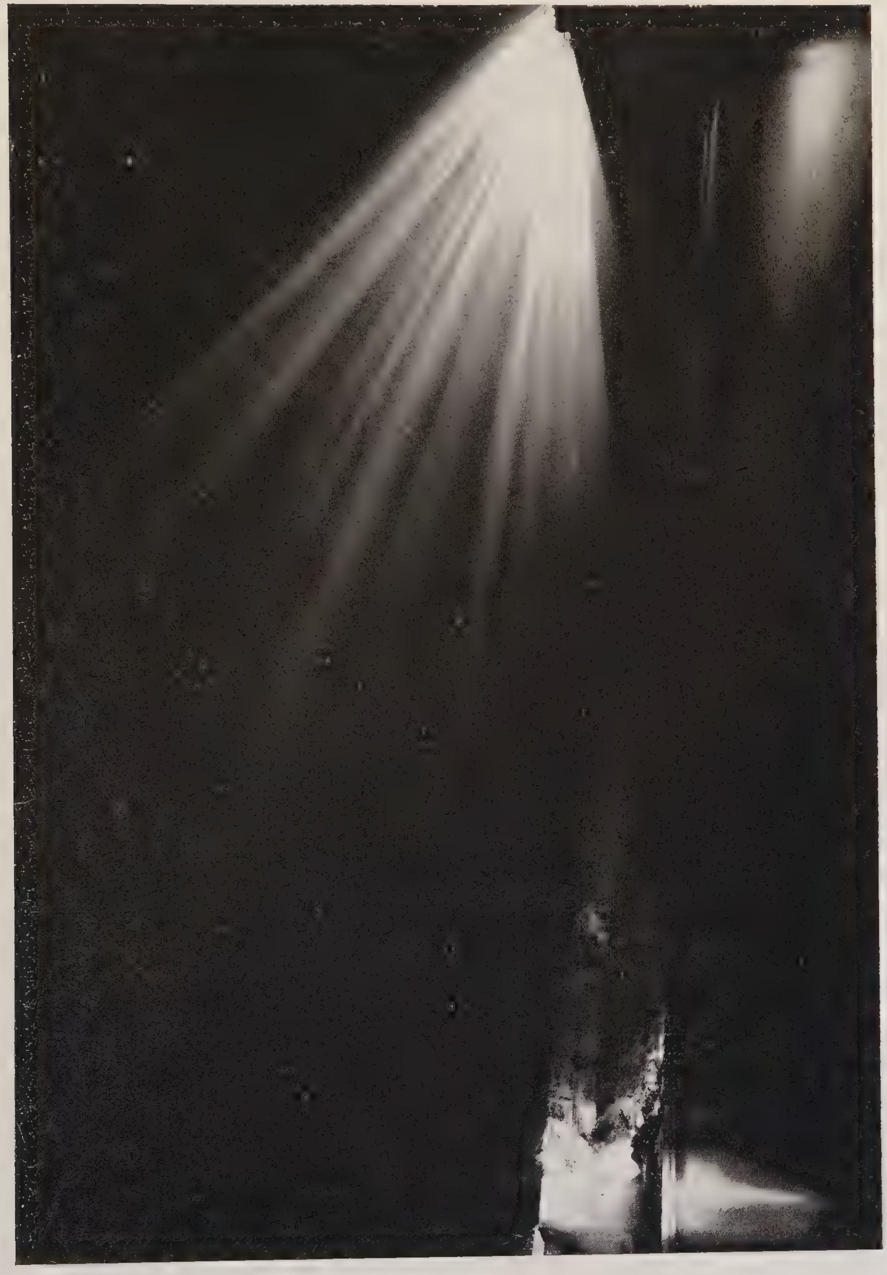

Fig. 166.—Floodlighting of Niagara. Beams from the twenty-four 36-inch Arc Projectors used for the floodlighting of the Falls.

Although still in its infancy, the realization of the potentialities of floodlighting in the revealing of the splendour of nature or the art of man, or as a handmaid to commerce and industry, is increasing rapidly. The recent introduction of colour effects has materially enhanced its possibilities, and each year sees it moving forward into a more extensive and more useful field of service.

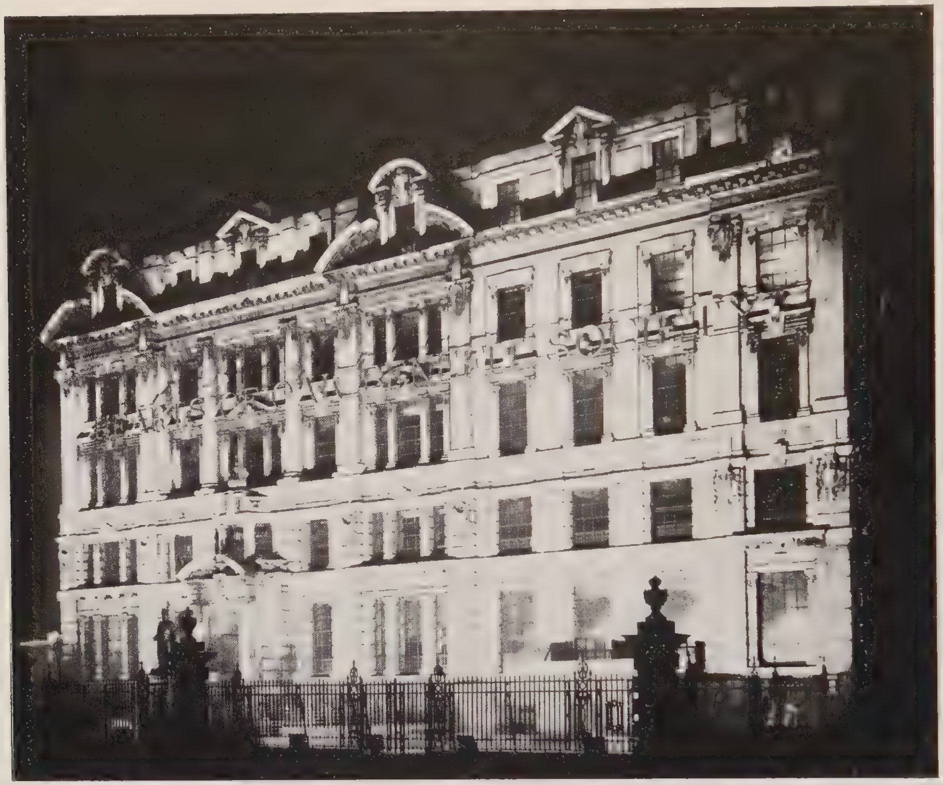

FIG. 167.—A WONDERFUL EXAMPLE OF FLOODLIGHTING BY WIDE-ANGLE RECTANGULAR PROJECTORS. Average intensity, 2·5 foot-candles; diversity, approx. 5:1.

Applications.—The applications of floodlighting are so numerous that to discuss them fully would require more than the whole of the present work. Many of the more usual are dealt with in the section devoted to Intensity of Illumination, and it will be sufficient at this stage to refer to a few of the newer applications and to certain installations suggesting further developments or possessing features of unusual interest.

The elaborately carved and beautifully decorated roofs and ceilings of lofty buildings are frequently enshrouded in gloom, with the result that their many beauties have remained unrevealed. In our older buildings the ravages of the 'beetle' occasionally render necessary the making of extensive repairs and renewals, and in such cases the provision of a good general illumination enabling work to be carried on continuously is of importance. Fig. 168 shows the roof of Westminster Hall, which was very successfully floodlighted during its restoration and reconstruction. A wonderfully carved and beautifully painted ceiling in one of London's famous mansions was recently floodlighted by projectors fixed outside and casting their beams upwards through glass panels. The result was a revelation in more senses than one, many hitherto unsuspected beauties being rendered visible.

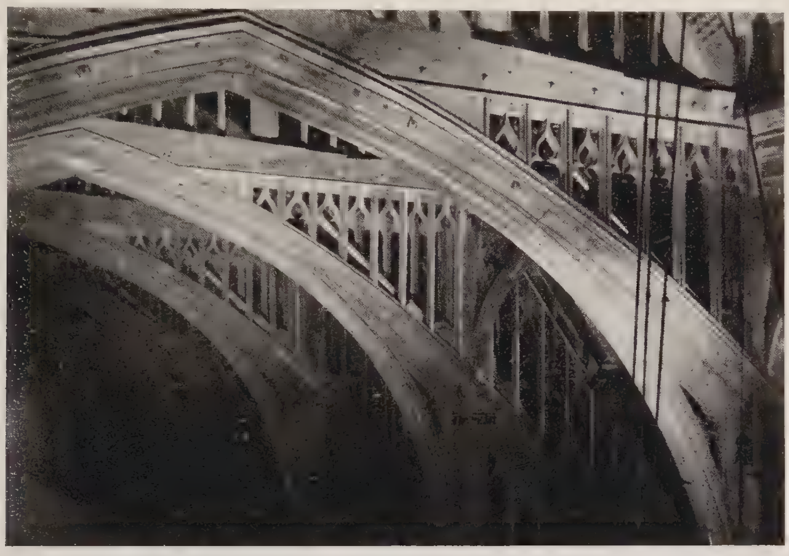

Fig. 168.—A Portion of the Roof of Westminster Hall, showing Floodlighting during its Reconstruction.

Another interesting application was the use of a portable floodlight for the lighting of individual pictures in a gallery, the daylight illumination of which left much to be desired. A number of floor sockets were installed. The floodlight, mounted in a small decorative cabinet provided with wheels and a flexible conductor and plug, is moved into any desired position and plugged into an appropriate socket. Groups of statuary can be successfully and economically illuminated in the same manner.

The growth of night flying has directed attention to the lighting of aerodromes and hangars. The latter are especially difficult to light in the ordinary way because of the extensive shadows cast by the machines. That the problem can be solved satisfactorily by the use of floodlights of a special type is demonstrated by Fig. 169. The illumination of the decks of seaplane-carriers is another instance of the service of floodlighting to aviation.

The wonderful floodlighting of the Rodeo and the Torchlight Tattoo in the Stadium at Wembley will be fresh in the memory of many. Figs. 170 and 171 show something of the results obtained, and are fertile in their suggestiveness as to the efficacy of floodlighting as an adjunct to pageants, carnivals, and spectacular displays.

The floodlighting of policemen on point duty, and the use of floodlights by fire brigades, are familiar to many and are ceasing to be looked upon as unusual.

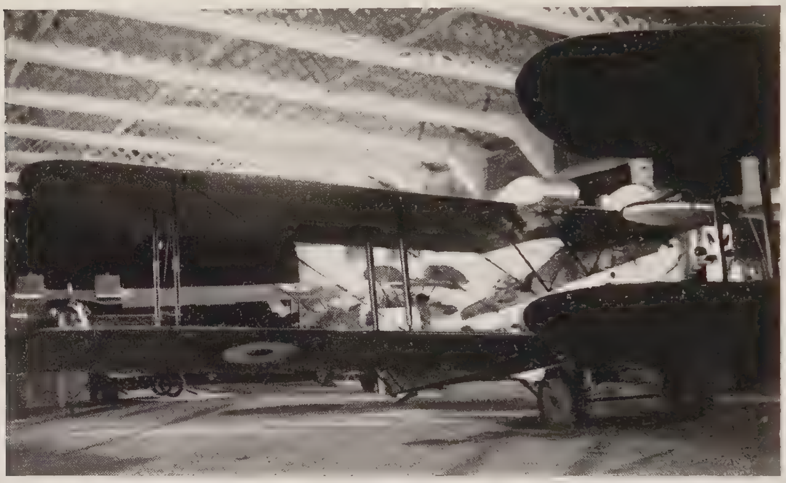

FIG. 169.—ILLUMINATION OF HANGAR BY FLOODLIGHTS OF SPECIAL TYPE. NOTE THE EVEN LIGHTING AND ABSENCE OF HEAVY SHADOWS UNDER THE LOWER WINGS OF THE MACHINES.

The realization by banks and insurance companies of the benefits to be derived from floodlighting their premises, particularly in the directions of increased protection and publicity, is rapidly increasing. That floodlighting, scientifically applied, can render the beauty of such buildings as great by night as by day is evident from Fig. 167.

Fig. 172 shows the famous Minneapolis Stone Bridge as it appears by night. Equally beautiful bridges span many of the rivers of Britain, and as, in many cases, electric-supply mains are actually carried over them, it is hoped that the future may see some of them illuminated by floodlighting in an equally pleasing manner.

The floodlighting of quarries and open mines is distinctly on the increase. Examples are shown in Figs. 173, 174, 175, and 176.

Another comparatively new application, which bids fair to increase, is the floodlighting of the open-air high-tension switch-gear now being installed by many supply authorities.

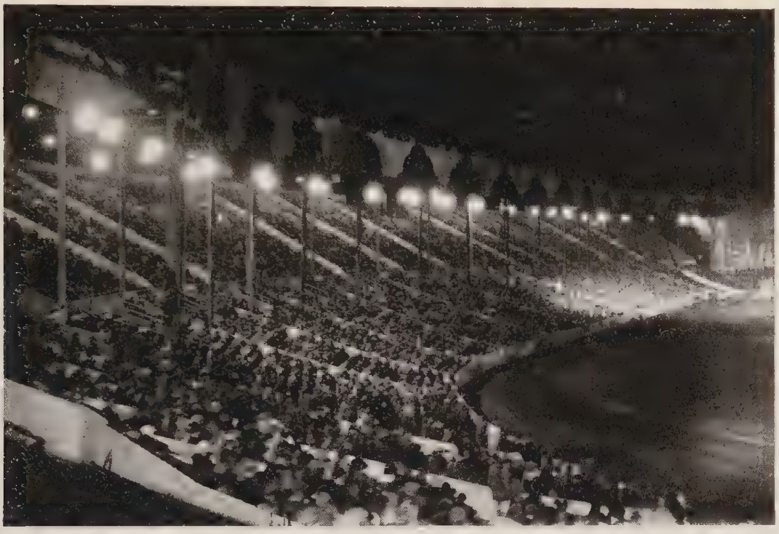

FIG. 170.—FLOODLIGHTING OF THE STADIUM AT THE BRITISH EMPIRE EXHIBITION DURING THE RODEO.

FIG. 171.—FLOODLIGHTING OF THE TORCHLIGHT TATTOO AT THE BRITISH EMPIRE EXHIBITION.

Enterprising builders and progressive supply companies are co-operating in the floodlighting of new houses, with advantage to both.

The houses, which are 'all electric,' are furnished and fitted throughout, and are open during the evening for inspection by prospective purchasers. Typical examples are illustrated in Figs. 177, 178, and 179.

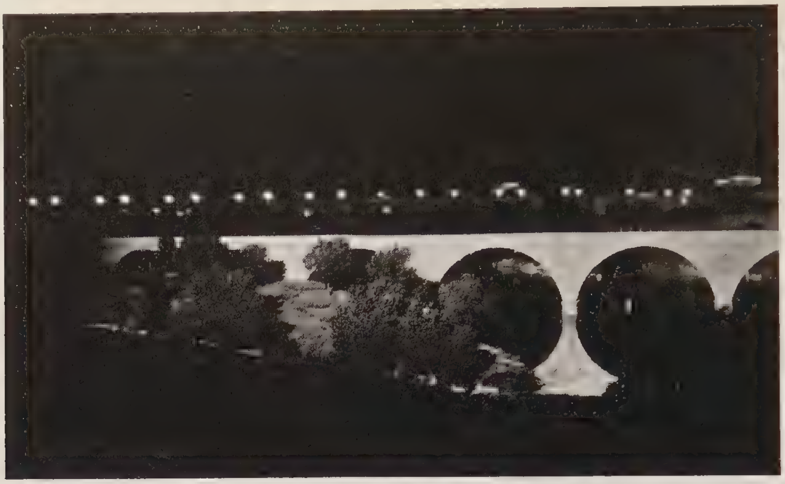

Fig. 172.—The famous Minneapolis Stone Bridge as it appears by Night.

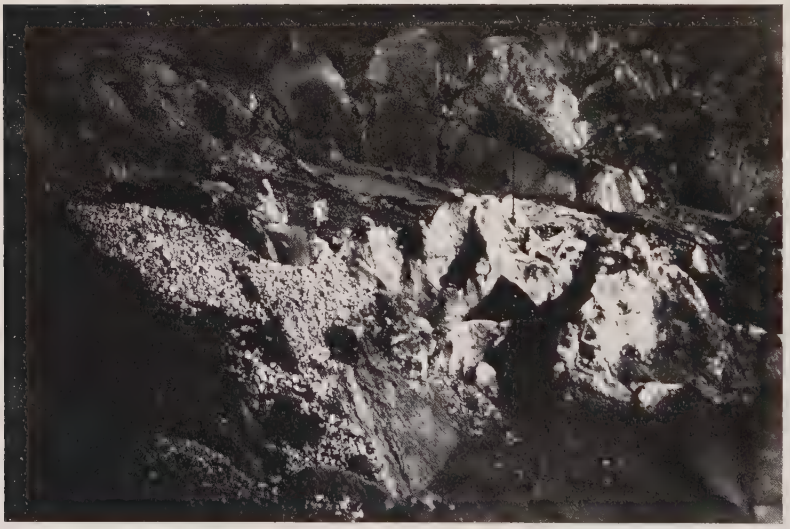

Fig. 173.—Floodlighting of a Chinese Open-cast Mine. The furthermost point illuminated is 200 yards from the source of light.

The remaking of important roads can best be carried on continuously by the floodlighting of the area under reconstruction during the hours of darkness. The saving of time effected in this way hardly requires emphasis in these days of congested traffic.

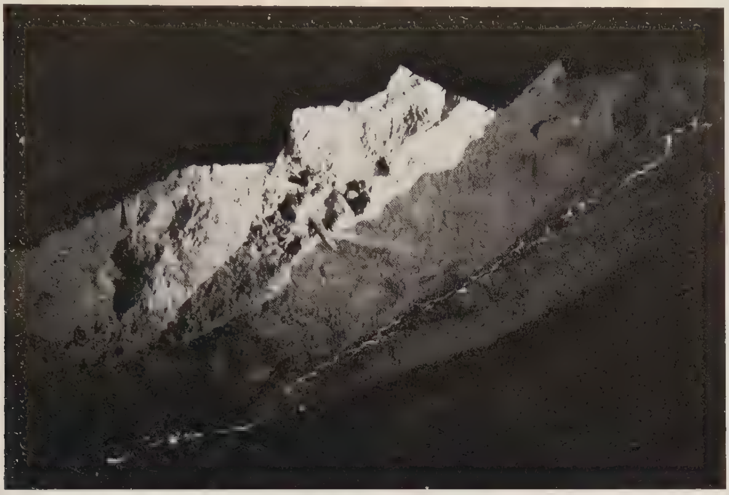

Fig. 174.—Floodlighting of a Quarry.

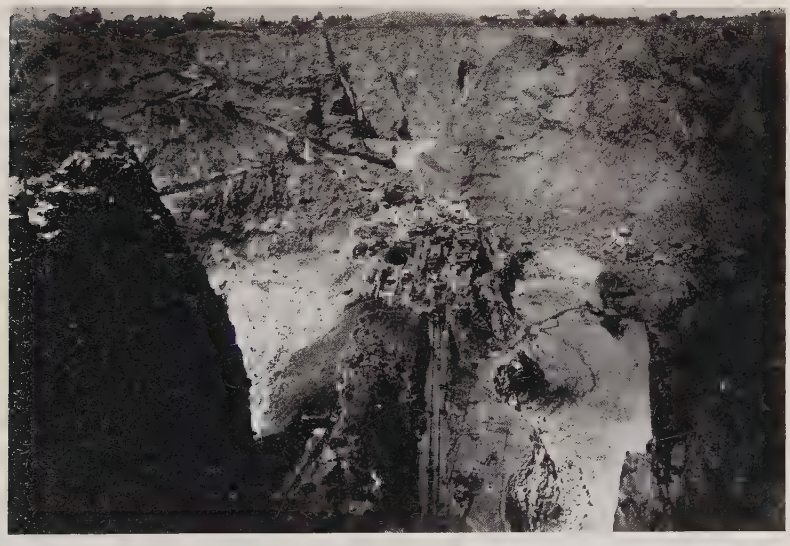

Fig. 175.—Daylight Photograph of the Premier Diamond Mine, Transvaal, South Africa. Fourteen batteries of floodlights are accommodated in huts round the edge of the mine, some of which can be seen.

The question of the floodlighting of railway goods yards, traffic-marshalling yards, sidings, etc., is receiving increasing attention, and the near future will probably see important developments in these directions.

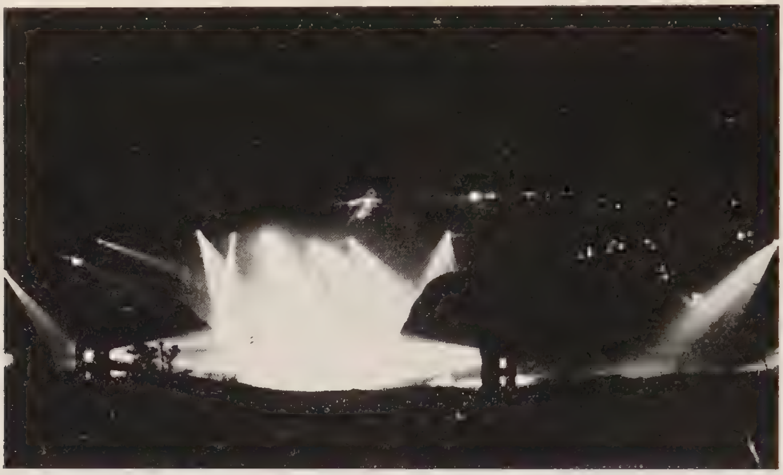

Fig. 176.—Premier Diamond Mine. Night Photograph showing Floodlighting. The illumination provided enables the mine to be worked twenty-four hours a day.

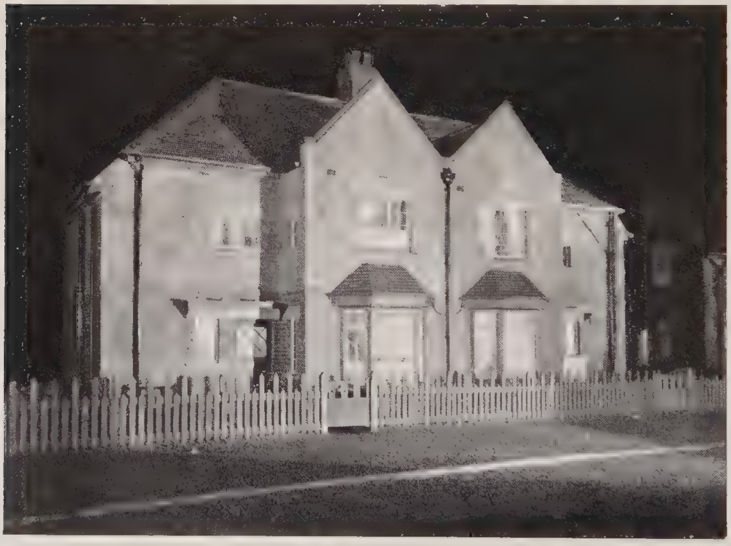

Fig. 177.—Floodlighting of 'All-Electric' Houses at Gateshead-on-Tyne.

Yet another problem in illumination which has been satisfactorily solved by the application of specially designed floodlights is the lighting of the leaf-drying sheds on tea plantations.

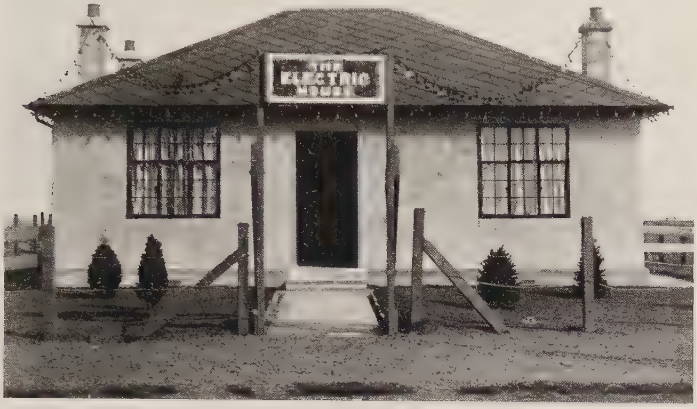

Fig. 178.

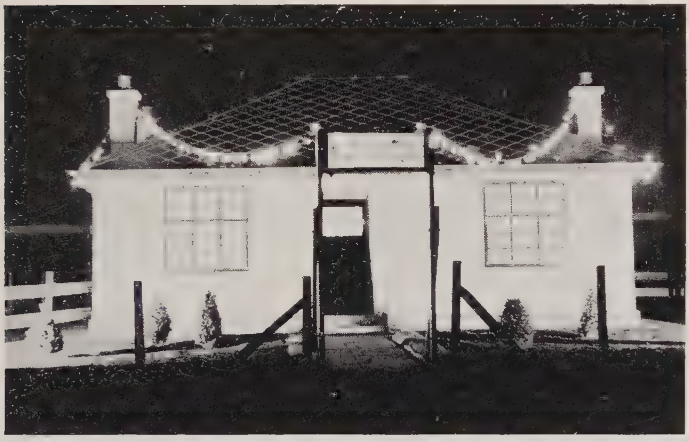

Fig. 179.

Floodlighting of Steel Houses. Day and Night Photographs of an interesting Example at Dundee.

The application of floodlighting illustrated in Fig. 162 is probably unique. The photograph reproduced shows the main entrance and part of the frontage of a well-known London store. The floodlights used are fixed in cellars, their light being projected on to the face of the building through glass panels in the pavement, one of which is visible in the foreground. Additional floodlights are concealed in the upper portions of the bronze lanterns, of 'Strozzi' type, fixed on each side of the doorway. The intensity is purposely on the low side, but the softly

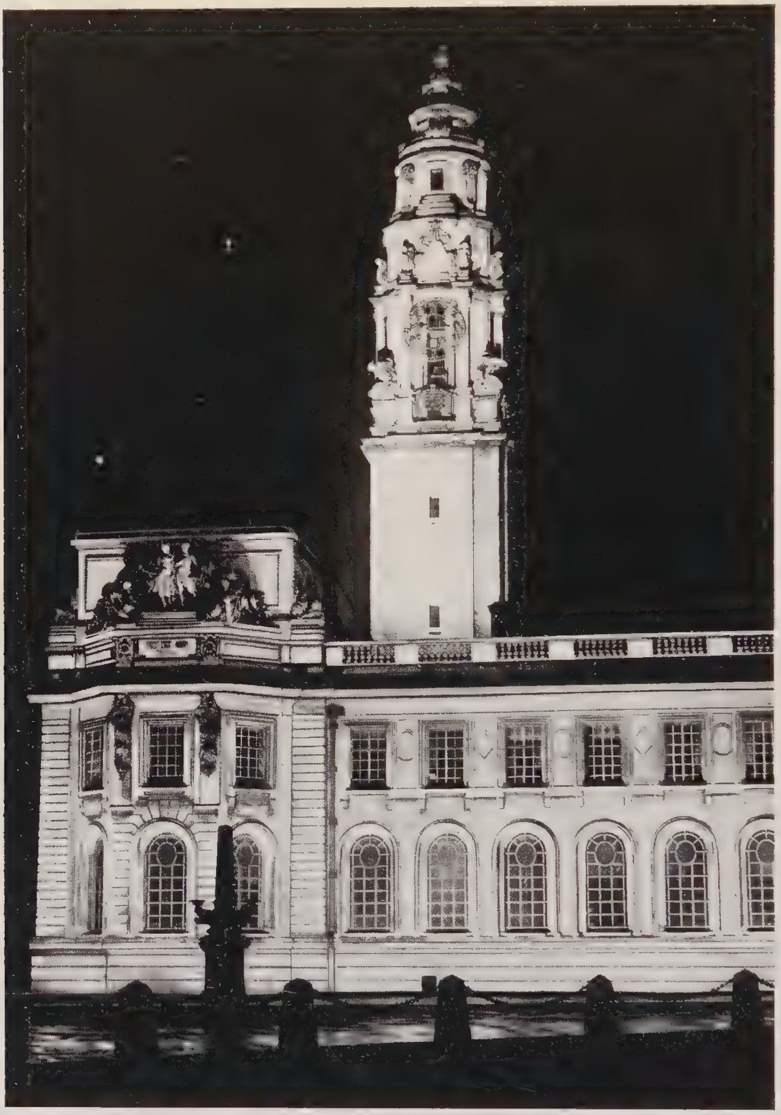

Fig. 180.—An Excellent Example of the Floodlighting of Municipal Buildings. Wide-angle floodlights fixed on the ground are used for the lower portion, the tower being illuminated by narrow-angle floods fixed on the roof.

luminous white stone front stands out conspicuously and is quite a feature of the thoroughfare.

Floodlighting offers a legitimate outlet for civic pride, and many municipalities are now taking advantage of the facilities which it affords for the illumination and beautification of their public buildings. Typical examples are illustrated in Figs. 180, 181, and 182.

Another application of the utmost importance from the point of view of public safety is the use of floodlights on foreign-going passenger ships. Paragraph 18 of Statutory Rules and Orders, 1924, No. 1289, stipulates that, 'On all foreign-going passenger ships in which the boat-deck is more than 30 feet above the water, provision shall be made for the illumination from the ship of the lifeboats when alongside and in process of, or immediately after, being launched.' Figs. 183 and 184 show floodlights specially developed for this new duty, whilst Fig. 185 illustrates the manner in which they are applied.

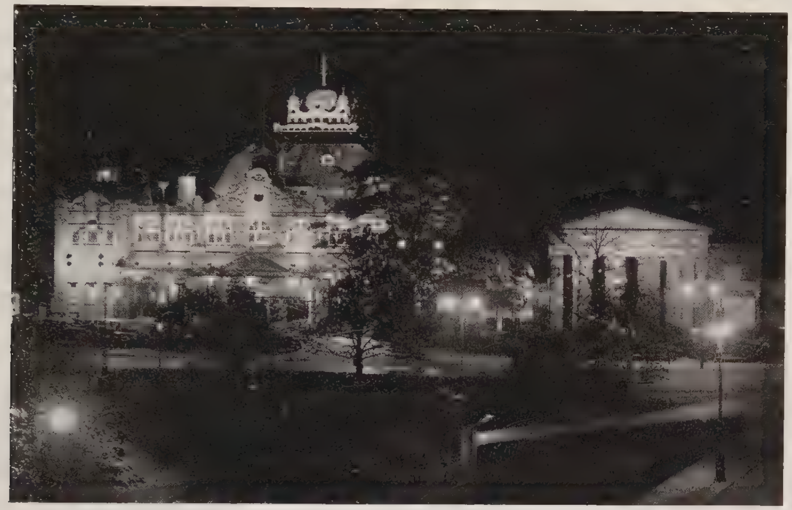

FIG. 181.—AN EXAMPLE ILLUSTRATING THE FLOODLIGHTING OF AN IMPORTANT PUBLIC HALL.

Many people still retain the mistaken impression that floodlighting is only applicable to outdoor work. This is no longer so. Indoors it is now coming into its own, and in buildings sufficiently lofty to permit of the mounting of the units at the necessary height floodlighting is giving surprising results. In the lighting of churches, for instance, its scope is almost unlimited. The illumination of the chancel and altar can be emphasized to any desired extent by projectors concealed behind the chancel arch, whilst the whole of the nave may be flooded with a soft and even illumination from specially designed fittings, of appropriately decorative form, fixed above the line of vision, and in which are incorporated floodlights of correct design.

A patented fitting of this description which embodies unusually interesting features is illustrated, and its construction shown, in Figs. 186 and 187. The general illumination is provided by the high-wattage lamp and one-piece silvered glass reflector shown, whilst the side panels of decorative diffusing glass are rendered softly luminous by the small lamps, which can, if desired, be of the colour-sprayed variety. The fitting is wired on two circuits in order that the large lamp may be switched off during the sermon. In those cases where it is desired that some light should reach the ceiling or roof, panels of diffusing glass are provided in the upper portion of the fittings.

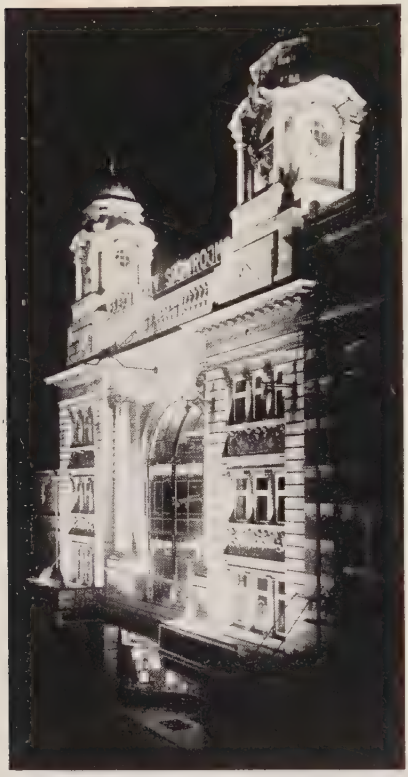

Fig. 182.—The Offices and Showrooms of a well-known Corporation Electricity Department floodlighted in Colour. The pillars on either side of the central arch were flooded in green, and the remainder of the building in amber.

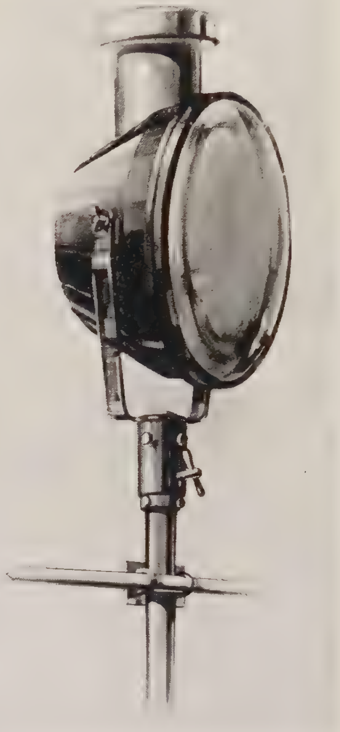

Fig. 183.—Marine-type Floodlight. Floodlights of this type fixed on the navigating bridge illuminate the hatchways and decks.

Many successful installations have already been made; Figs. 188 and 189 show one such, the former being a daylight photograph showing the location of the fittings (and, incidentally, the daylight illumination), and the latter a night photograph showing the illumination of the body of the church. Fig. 190 illustrates an equally pleasing installation in a church of quite a different type, in which the fittings are suspended from the apex of each arch. The floodlighting of the chancel and altar is worthy of note. Fig. 191 shows another interesting example of interior floodlighting; in this case the background of the chancel, which consists of an exceedingly beautiful Venetian mosaic, is illuminated by floodlights concealed behind the front arch. The work is executed in colours, and its effect when illuminated is very pleasing.

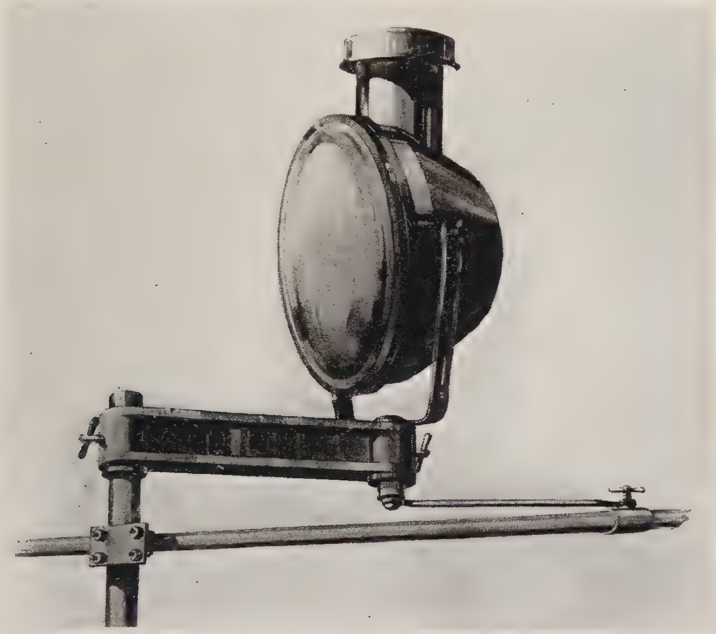

Fig. 184.—A Special Type of Floodlight developed for use during the Launching of Boats or the Docking of the Vessel.

Choice of Equipment.—The designer of floodlighting installations has at his disposal a range of equipment which is continually being increased by the introduction of additional types developed to meet the requirements of new applications.

The housings of present-day floodlights are usually circular in shape and constructed of cast-iron or stout sheet-copper. The latter is preferable from the desiderata of lightness, strength, and durability.

Ready access to the lamp is of importance. A satisfactory focussing device should always be incorporated and a universal trunnion movement provided for easy adjustment of the position of the ultimate field. Front glasses should have a low absorption factor, should be, preferably, of the domed variety and, in the larger sizes, should always be of heat-resisting glass.

Ample ventilation should be insisted upon, as otherwise the life of the lamp may be seriously impaired. It is *possible* to construct floodlights which are totally enclosed, but the provision of a surface capable of radiating the heat sufficiently quickly involves, in the larger sizes, so great an increase in both bulk and weight that their use is rarely desirable and is frequently impossible.

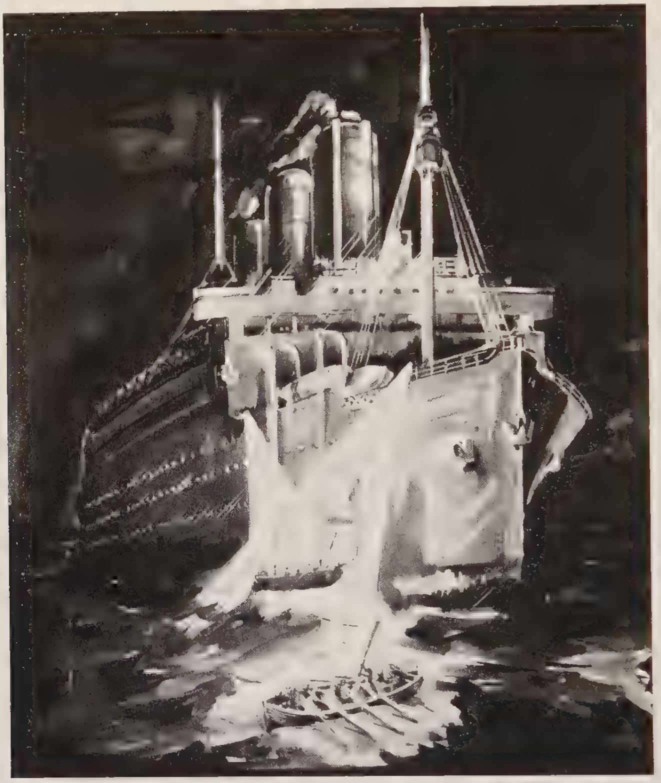

Fig. 185.—Application of the Floodlights illustrated in Fig. 184.

A new type of floodlight of rectangular shape, and provided with mirror reflecting surfaces of special shape, has recently been introduced by one prominent manufacturer. Its beam angle is exceptionally wide and it has already proved of value in the particular application for which it was developed, namely, the efficient and economical illumination of large surfaces from below. Its construction is illustrated in Fig. 192, and some of its applications in Figs. 167, 180, 208, and 233.

Floodlight reflectors are now almost invariably of silvered glass, since to control and direct the light into the relatively narrow beams required it is necessary to use a specularly reflecting surface possessing a high initial coefficient of reflection and capable of retaining its efficiency for prolonged periods. Classification of the large number of patterns available discloses the fact that they may, in general, be divided into two broad groups: those in which standard gas-filled lamps of from 100 to 1,500 watts are used and those employing the special 250-watt or 500-watt round-bulb floodlighting lamps with their more concentrated filaments. Typical examples of both types are illustrated in Figs. 193 to 198, and typical light-emission curves in Fig. 199.

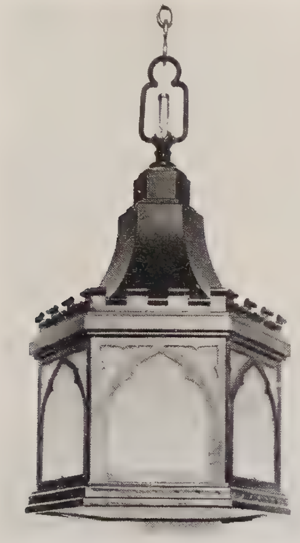

Fig. 186.—Fitting for Interior Floodlighting.

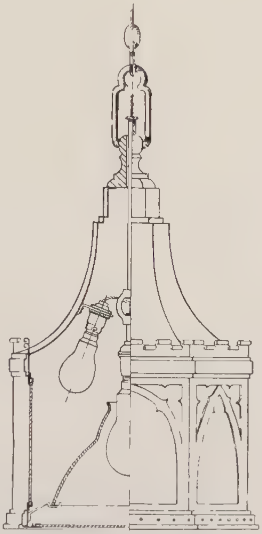

Fig. 187.—Construction and Arrangement of Fitting shown in Fig. 186.

Floodlights using the standard lamp are generally of the medium or wide-angle type, and are used for the illumination of large surfaces at short range. Conversely, those employing the concentrated-filament floodlighting lamps are of the narrow-angle type, have, as a rule, a higher beam efficiency, and are used in those cases where it is required to project the light from a distant point, to illuminate small objects or areas to a high intensity, or to introduce directional illumination. Floodlights of the former type are available having beam angles of from 20 to 90 degrees, and of the latter type with beam angles as low as 8 to 10 degrees. Both types are designed to enable the beam angle and consequently the area of the illuminated field to be varied slightly by moving the lamp along the axis of the reflector to a position behind, or in front of, the focal point. This feature allows a certain latitude to the designer, and enables individual projectors to be adjusted *in situ* as required. The limit of such movement is reached when any unevenness becomes apparent in the illuminated field.

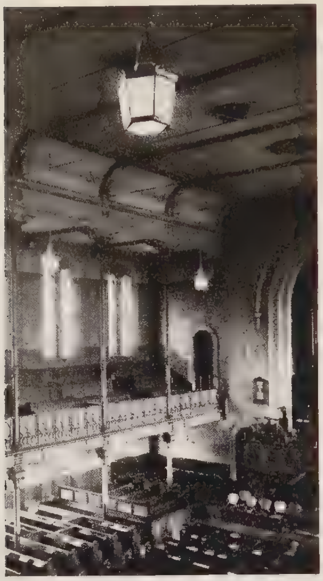

Fig. 188.—Daylight View showing Interior Floodlight Fittings in position.

Equipment should be selected with due regard to the factors involved, and its choice should invariably be verified by calculation.

It should also be recognized that a variety of equipment may, if necessary, be utilized in a single installation. Circular and rectangular floodlights giving respectively wide-angle and narrow-angle beams are frequently used in conjunction with excellent effect, as is shown by the illustrations reproduced in Figs. 180 and 233.

Location of Equipment.—The location of the equipment is a vital factor in the designing of floodlighting installations. The type of floodlights to be used depends in large measure upon the position in which they must be fixed. It would, for instance, be impracticable to use narrow-angle projectors for the illumination of a large surface if it were essential for them to be supported by brackets attached to the face of the building. It would be equally impracticable to use wide-angle projectors if the only position in which they could be fixed were, say, 150 to 200 feet away.

The floodlighting of buildings, monuments, war memorials, etc., can be successfully carried out by the employment of projectors located (*a*) on the face of the building to be illuminated (see Figs. 200, 201, and 202); (*b*) on ornamental brackets, as shown in Figs. 203 and 204, attached to the face of the building (see Figs. 205 and 206); (*c*) on porches or verandahs projecting from the building (see Fig. 207); (*d*) on the ground in front of the building or subject (see Figs. 167, 177, 179, 180, 208, 209, and 234); (*e*) below ground-level in front of the building or subject (see Fig. 162); (*f*) on standards in front of the building or subject (see Fig. 210); (*g*) on other buildings some distance from the building or subject, usually on the opposite side of the street (see Figs. 211, 212, 213, and 214).

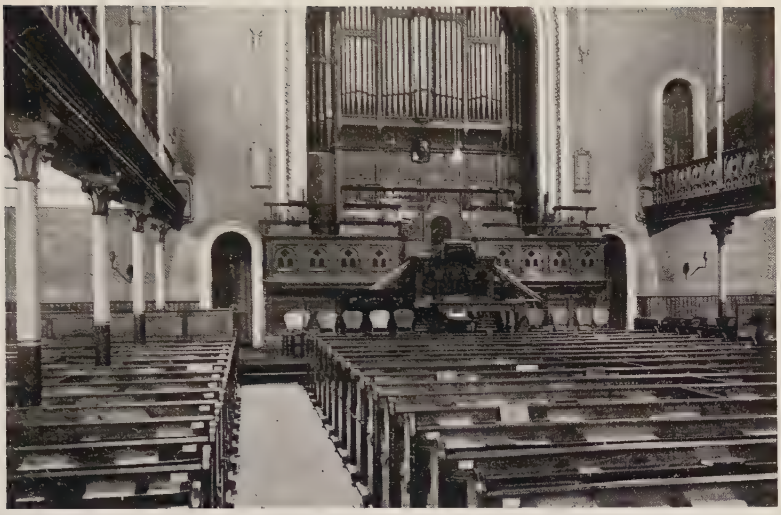

Fig. 189.—Night View showing Illumination from Fittings illustrated in Fig. 188.

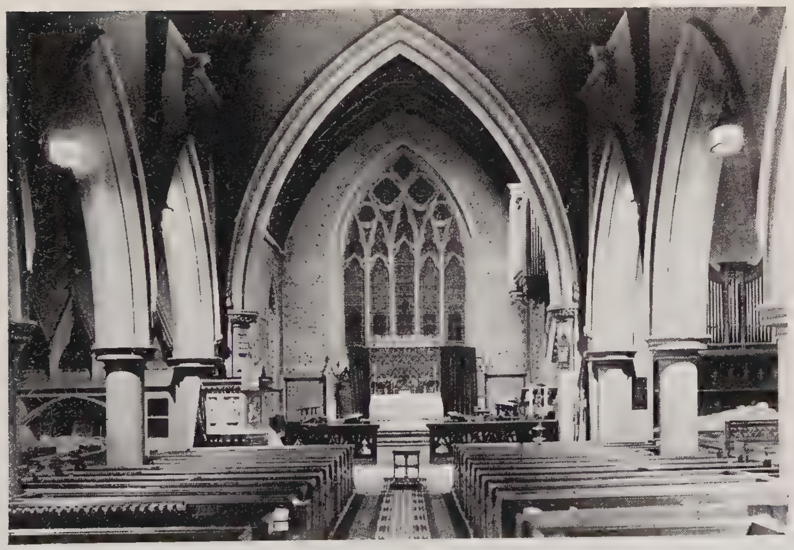

Fig. 190.—Floodlighting of Chancel. The floodlights used are concealed behind the chancel arch.

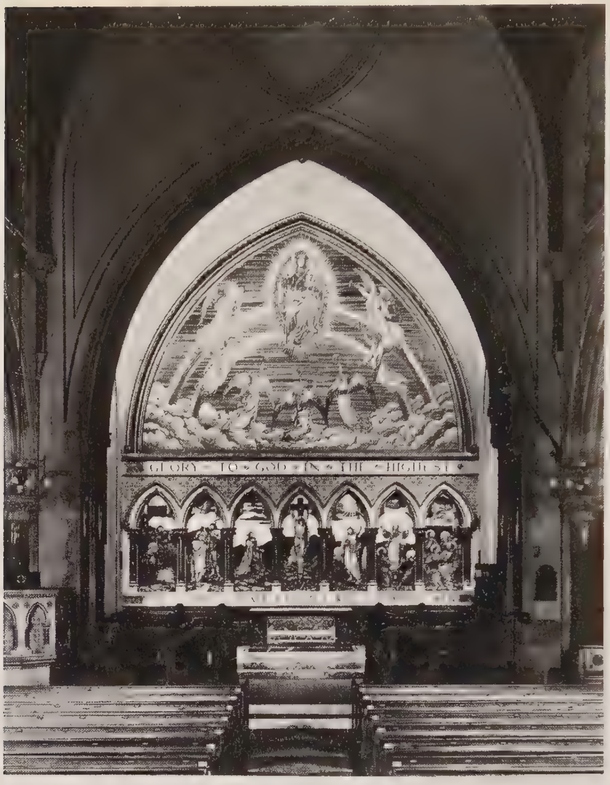

Fig. 191.—A Wonderful Venetian Mosaic, the beauty of which is enhanced by Floodlighting.

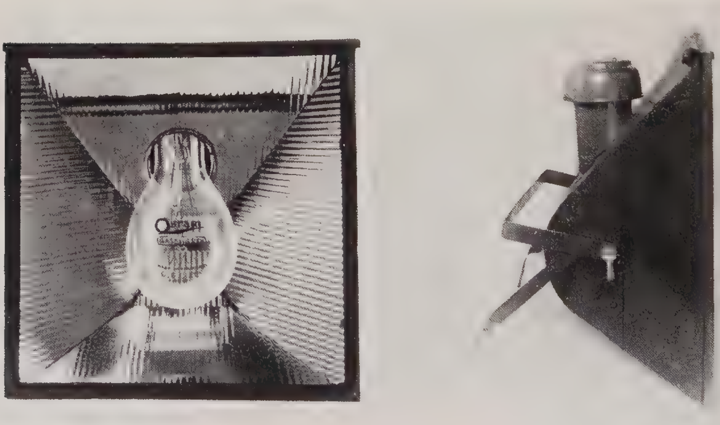

Fig. 192.—New Type of Wide-angle Floodlight of rectangular shape.

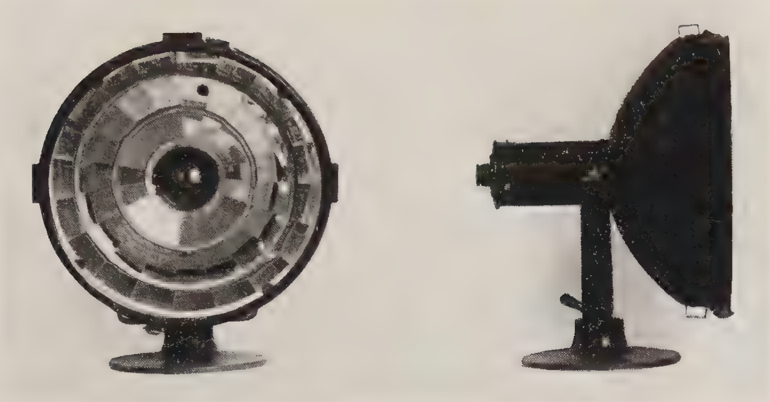

FIG. 193.

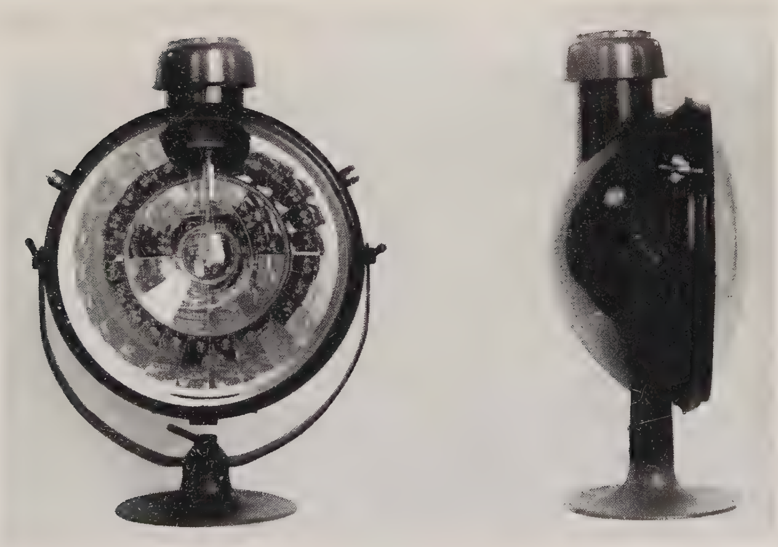

FIG. 194.

TYPICAL EXAMPLES OF FLOODLIGHTING EQUIPMENT.

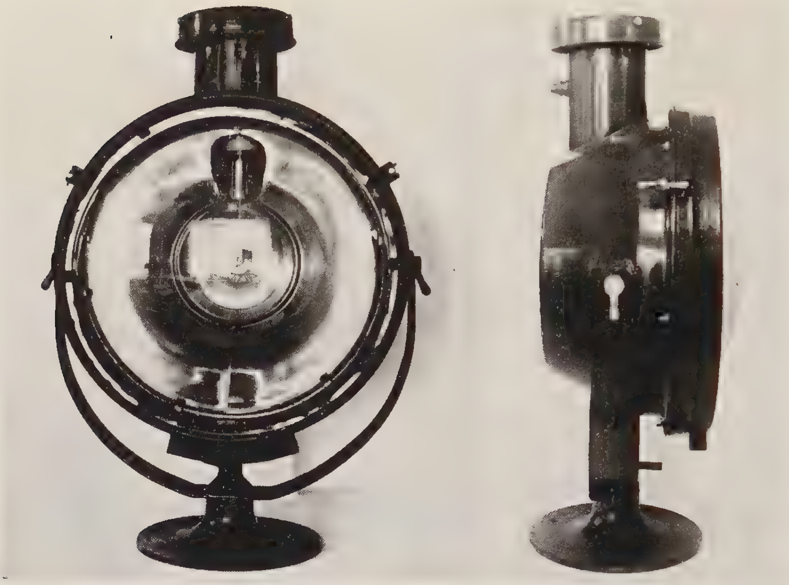

Fig. 195.

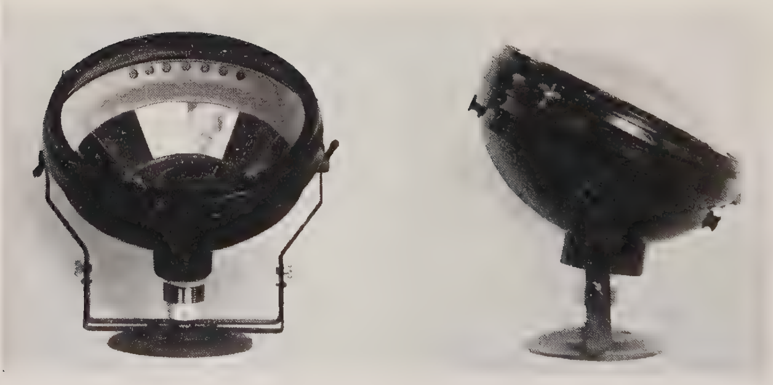

Fig. 196.

Typical Examples of Floodlighting Equipment.

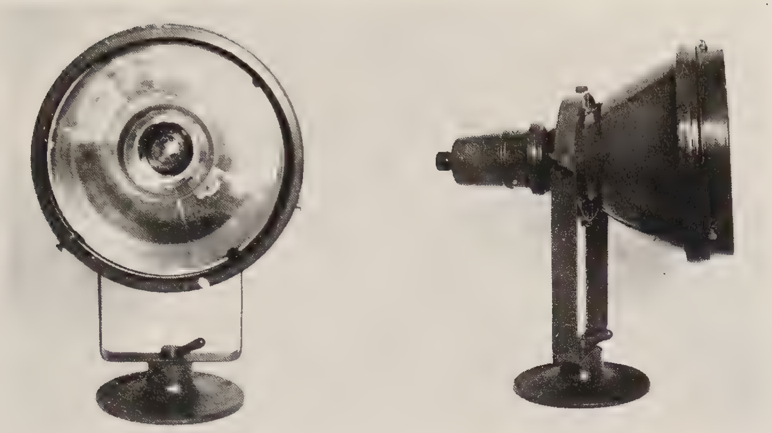

Fig. 197.

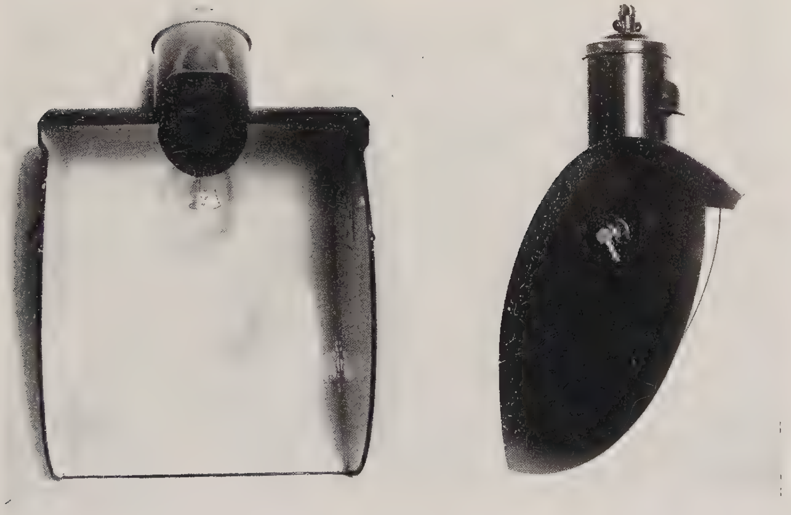

Fig. 198.

Typical Examples of Floodlighting Equipment.

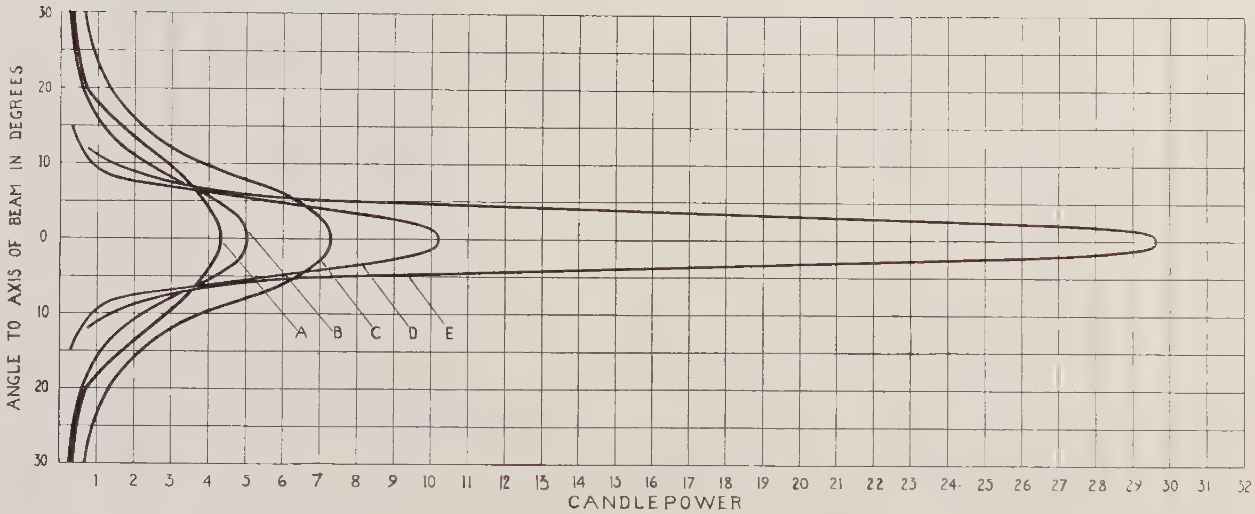

FIG. 199.—CHARACTERISTIC LIGHT EMISSION CURVES OF TYPICAL FLOODLIGHTS. A and B wide-angle, C medium-angle, D and E narrow-angle beams.

(Each division in the candle-power scale represents 3,000 apparent candle-power.)

In the floodlighting of advertising signs, poster hoardings, and the like, the projectors can frequently be located on convenient buildings (see Figs. 215 and 216), can be accommodated on a projecting verandah or balcony below the sign (see Fig. 217), or can be supported by brackets attached to either the top (see Figs. 218 and 219) or the bottom (see Fig. 220) of the sign itself according to the design of the equipment used. In certain special cases, such as that of the railway notice-board illustrated in Fig. 221, the floodlights can stand on the ground, or can be supported by the wall or railing in front of the board.

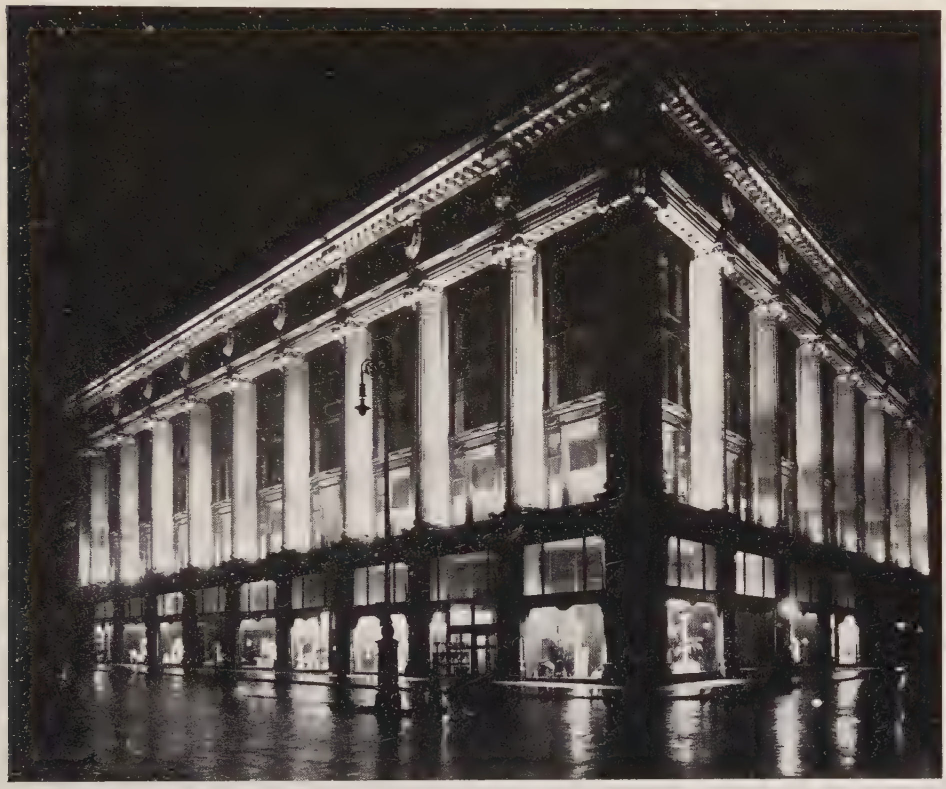

FIG. 200.—ONE OF THE EARLIEST EXAMPLES OF FLOODLIGHTING IN ENGLAND. THE FLOODLIGHTS ARE FIXED ON THE BUILDING.

The illumination of domes and alcoves such as those shown in Figs. 222 and 223 can usually be carried out effectively by floodlights concealed from view by the front of the arch.

When considering the positions in which the projectors are to be fixed, it should be realized that ease of access is of importance from the point of view of lamp renewals and cleaning.

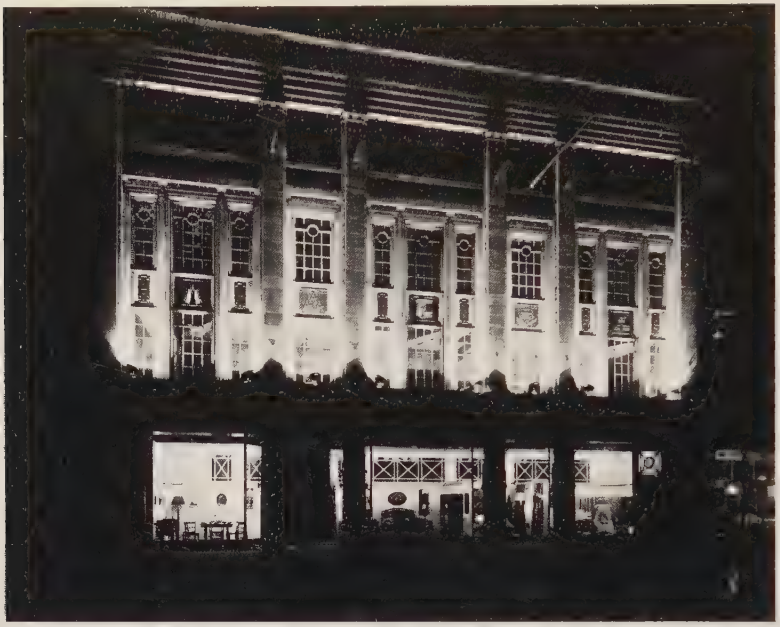

Fig. 201.—Another well-known Example of this method of treatment.

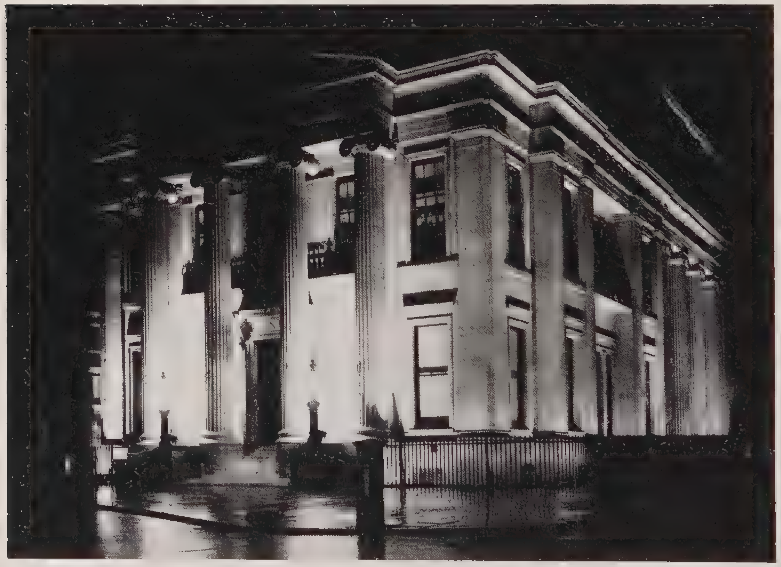

Fig. 202.—Illumination of a notable Government Building.

The arrangement of the projectors should be carefully studied in every case, as sometimes a slight change in their position makes a considerable difference in the result obtained. Where a number are used, they should, if possible, be arranged in two or more banks in

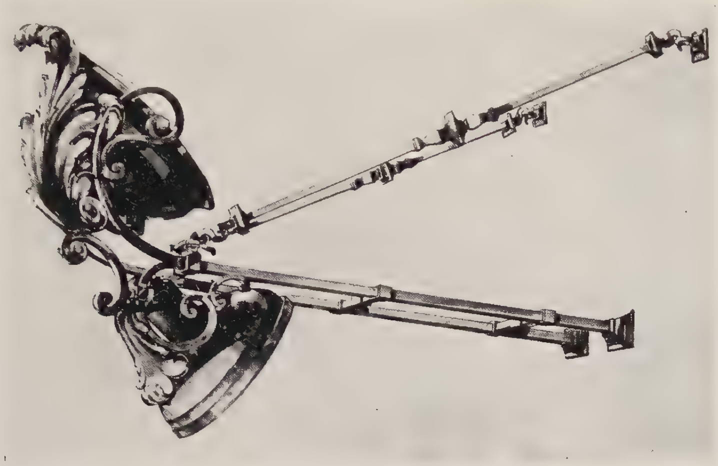

Fig. 203.

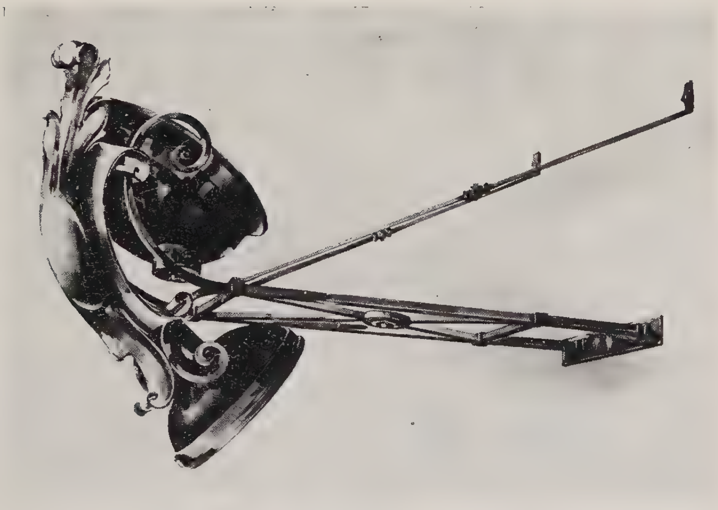

Fig. 204.

Examples of Ornamental Brackets for supporting Floodlights on Buildings.

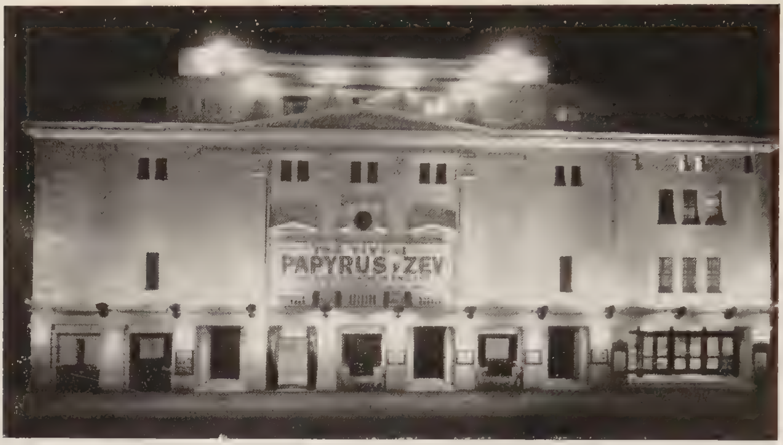

Fig. 205.—Example of Floodlighting by Projectors carried by Brackets of the type shown in Figs. 203 and 204.

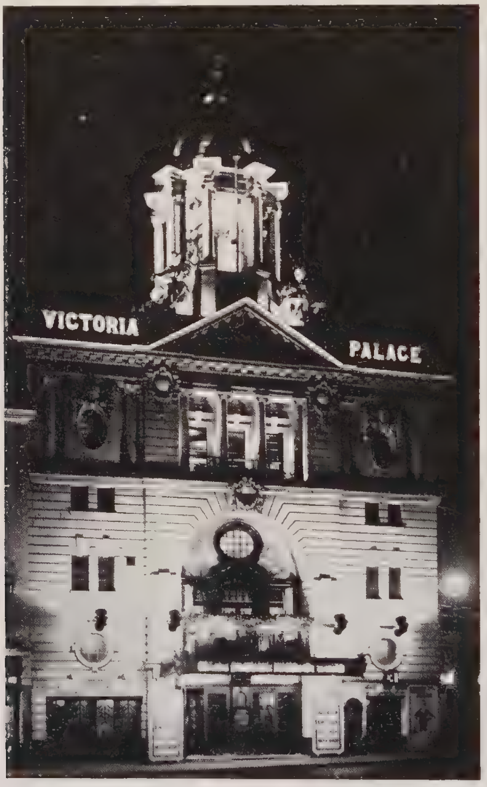

Fig. 206.—Another Example showing Floodlights carried by Brackets.

order that the beams may be overlapped. Such overlapping is of assistance in the elimination of harsh shadows and the securing of a more even and more pleasing effect. Except when strongly directional lighting is required the whole of the surface to be illuminated should receive at all events a certain amount of light from at least two directions.

Where only a small number of projectors are used, it is desirable to locate them at the two ends of the subject, as by arranging them in this way and crossing the beams a greater area can be illuminated than is possible if the arrangement is such that the beams are at right angles to the illuminated surface (see Fig. 224).

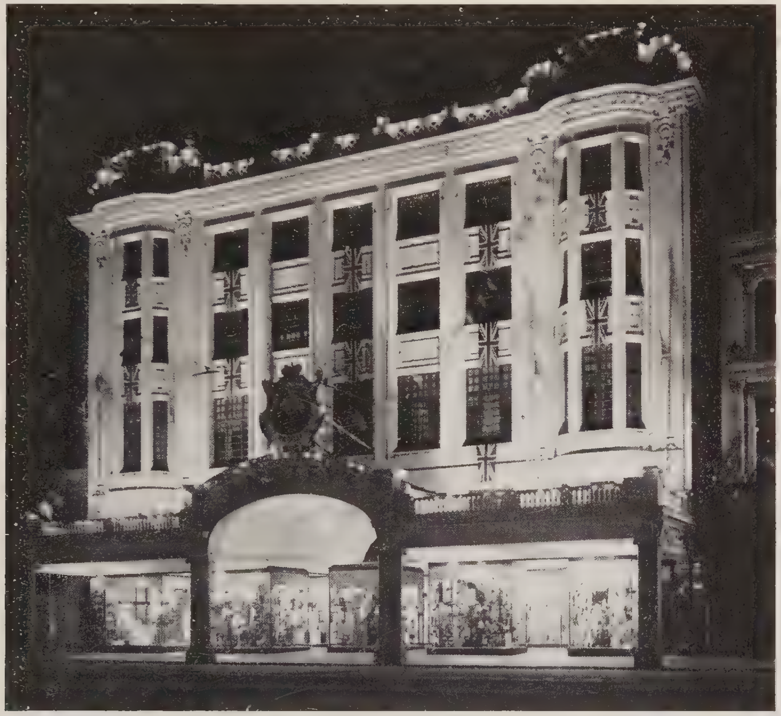

Fig. 207.—A South African Example. In this installation the floodlights are mounted upon the projecting balcony shown.

Intensity of Illumination required.—The determination of the intensity required for the satisfactory illumination of any specific area, or object, involves the consideration of a number of factors. The nature of the work to be performed in, for instance, the clearing of a building site, the excavating for foundations, or the erection of a new structure, the sport or recreation to which an open area is to be

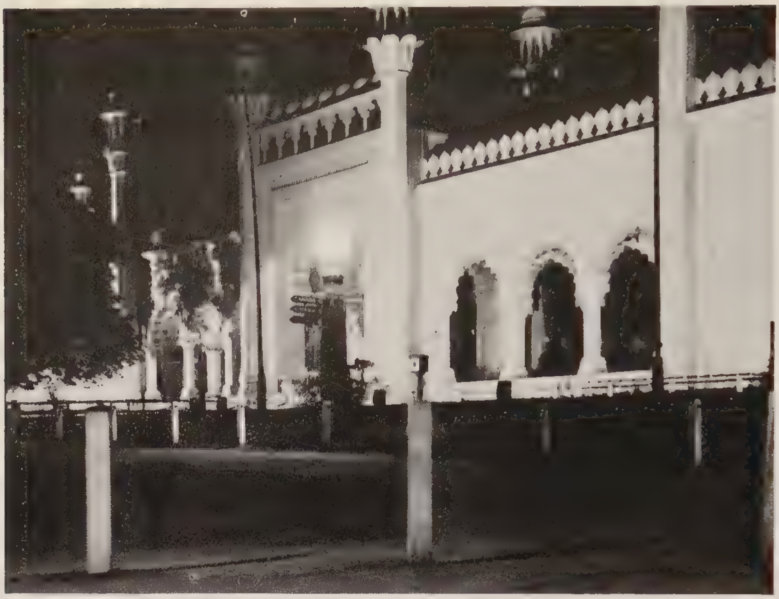

FIG. 208.—INDIAN PAVILION, BRITISH EMPIRE EXHIBITION. AN INSTALLATION OF FLOODLIGHTING IN COLOUR. THE PROJECTORS USED WERE THE WIDE-ANGLE RECTANGULAR TYPE ILLUSTRATED IN FIG. 192.

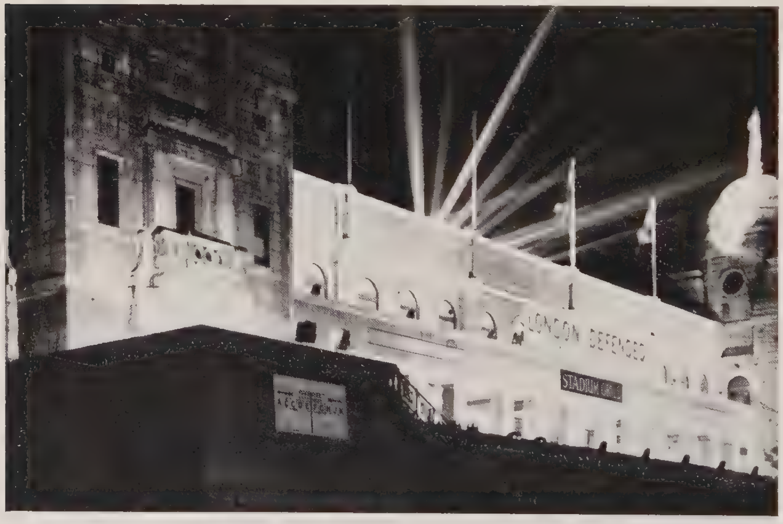

FIG. 209.—ANOTHER INTERESTING EXAMPLE. THE RECTANGULAR PROJECTORS USED ARE SHOWN IN THE FOREGROUND.

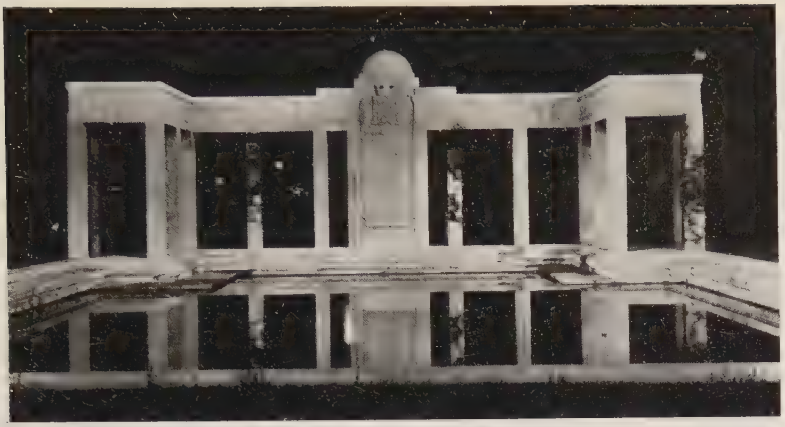

Photo by G. W. King, Brighton.

FIG. 210.—FLOODLIGHTING OF WAR MEMORIAL. THE PROJECTORS USED ARE MOUNTED ON ORNAMENTAL WROUGHT-IRON STANDARDS.

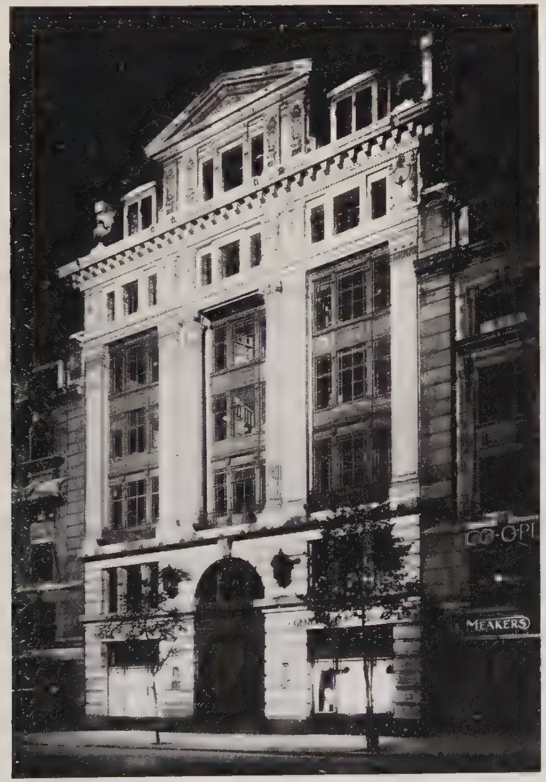

FIG. 211.—MAGNET HOUSE, KINGSWAY. A TYPICAL EXAMPLE OF THE FLOODLIGHTING OF BUSINESS PREMISES.

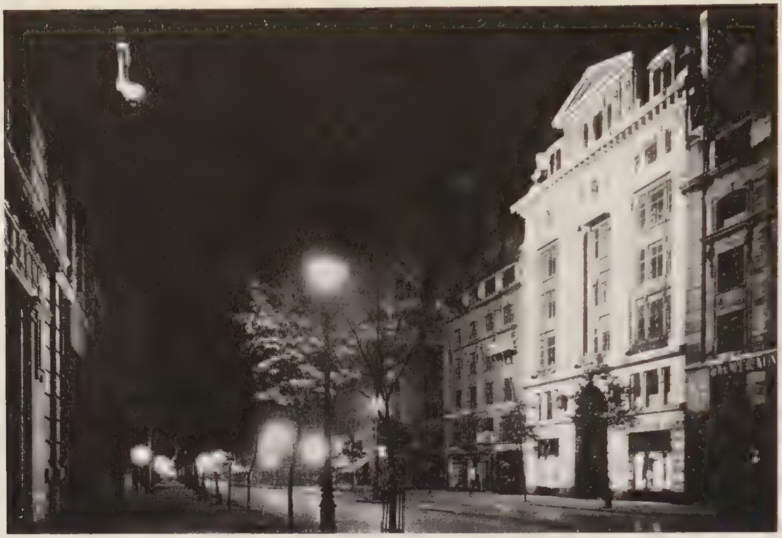

Fig. 212.—Showing the Method adopted for the Illumination of the Building shown in Fig. 211.

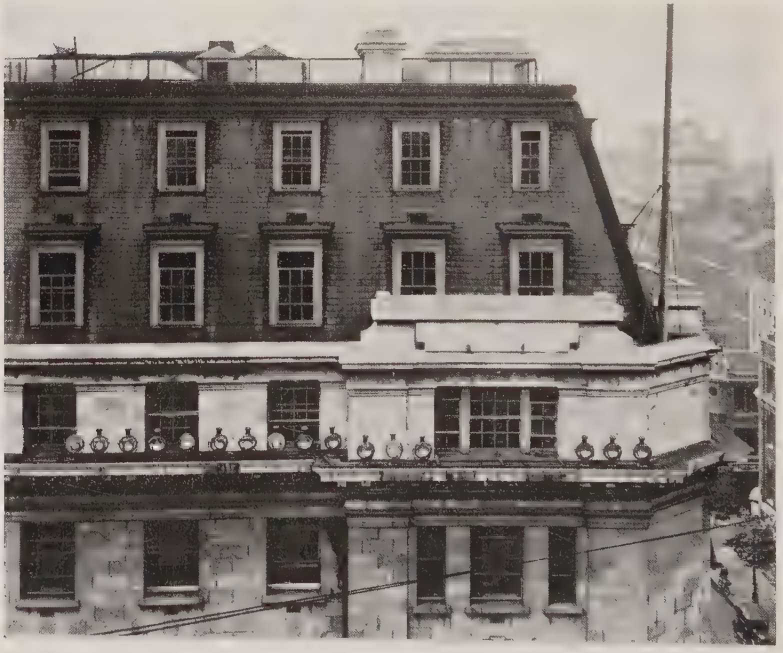

Fig. 213. -The sixteen Projectors used for the Floodlighting shown in Fig. 211 are mounted upon a projecting ledge of a building on the opposite side of the thoroughfare, and are controlled by automatic time switches.

devoted, the nature, magnitude, and to some extent the colouring of such spectacular settings or performances as are likely to be presented in an open area, are matters of importance.

In the floodlighting of buildings, monuments, statues, or the like, the intensity required will depend upon the nature of the object, the material of which it is composed, the brightness or otherwise of its surroundings, and the background against which it will normally be viewed. It will, therefore, be apparent that a light stone building located in a brightly lighted shopping district, or a monument or statue of similar material erected in a well-lighted city square, will require a higher intensity of illumination than a similar building, or object, located amidst less brightly lighted surroundings, as, for instance, a poorly illuminated district, a public park or garden, or the open country. Conversely, under equal conditions of surrounding illumination, a dark object will require a higher intensity than a lighter one. In the case of advertisement hoardings, extensive display signs, chimney signs, and the illumination of buildings for purely advertising purposes, the attractive power of high illumination should be properly appreciated. It is rarely possible in such cases to over-light if the

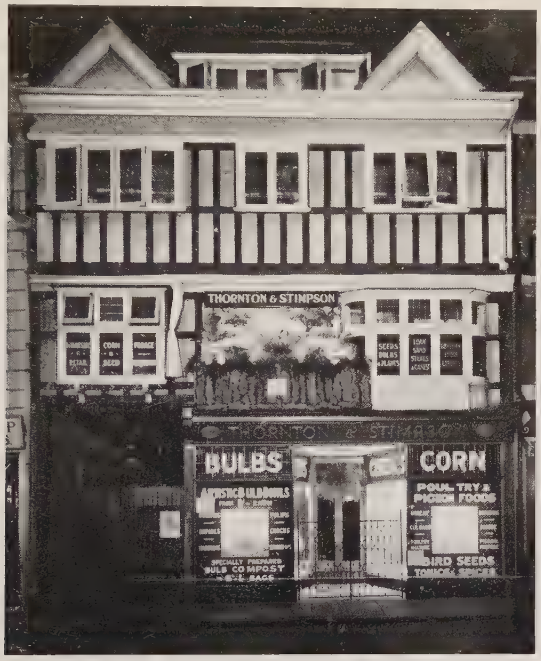

Fig. 214.—A further Example in which the Projectors are fixed on the opposite side of the street.

installation is correctly designed. To render a sign or structure conspicuous in the midst of bright surroundings it *must* be illuminated to a really high intensity; layer upon layer of light must be projected upon it; half-way measures are entirely useless, and have no place in floodlighting for artistic effects. From the point of view of contrast the question of the background against which an object is to be viewed

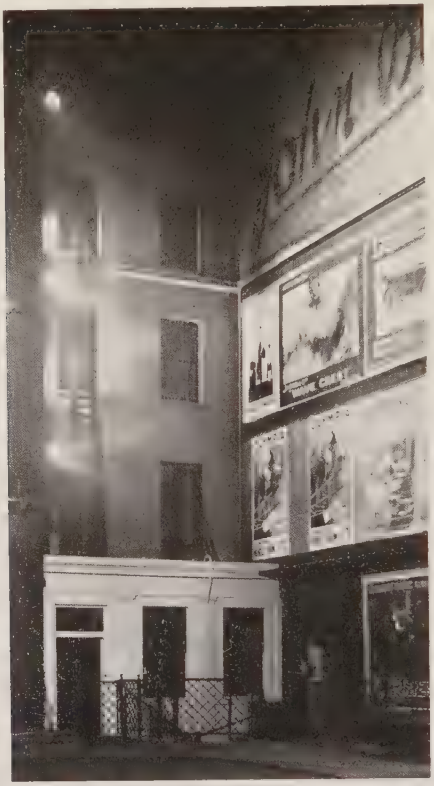

FIG. 215.—THE FLOODLIGHTING OF AN ADVERTISEMENT HOARDING. THE ILLUSTRATION SHOWS THE LOCATION OF THE PROJECTORS.

is of importance apart from the brightness or otherwise of its immediate surroundings. A light object illuminated to a given intensity will present a far more beautiful appearance if viewed against the night sky or a background of distant foliage, than if backed by buildings of approximately the same colour.

Whilst individual installations must, for the reasons previously explained, be dealt with on their merits, the intensities given in the following tables will be found useful as indicating desirable levels of illumination in typical applications of floodlighting. The values stated are for white light. If colour screens are employed it may be necessary to increase the intensity. When computing intensity values it may be noted that full moonlight equals approximately $\frac{1}{40}$th foot-candle.

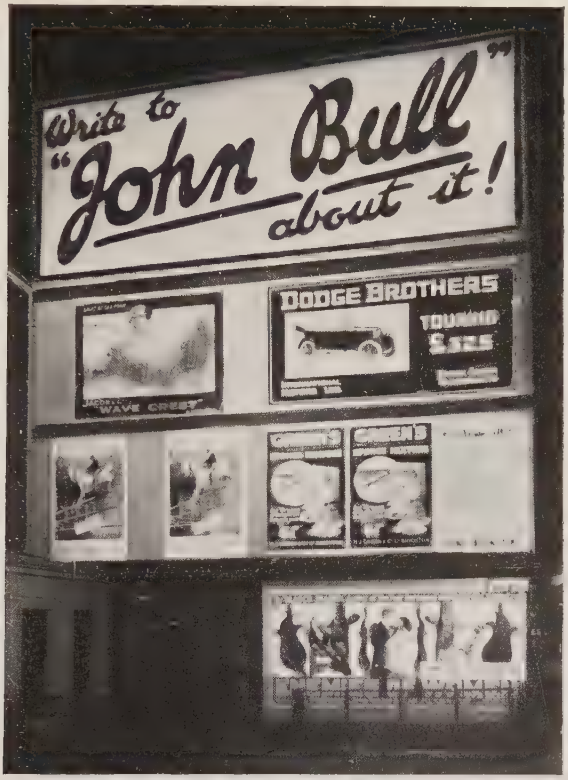

Fig. 216.—The Illumination on the Hoarding from the Projectors shown in Fig. 215.

TABLE XXII

TYPICAL APPLICATIONS OF FLOODLIGHTING, WITH RECOMMENDED AVERAGE FOOT-CANDLE INTENSITIES OF ILLUMINATION FOR EACH

Nature of Subject	Foot-Candles
Bathing pools, open-air baths, and bathing beaches	0·25 to 2
Building construction	2 to 4
Building excavation	1 to 2
Building exteriors, monuments and statues	(See Table XXIII)
Church windows (stained glass)—	
Light surroundings	10 to 20
Dark surroundings	5 to 10

TABLE XXII—*continued*

NATURE OF SUBJECT	FOOT-CANDLES
Circus rings	2 to 6
Fire-brigade and salvage work	2 to 6
Flags	5 to 10
Loading docks, wharves, etc.	1 to 2
Outdoor sports—	
Athletics, croquet, football, polo, putting greens, clock golf, etc., racing tracks (cycle, motor, etc.)	2 to 6
Pageants and spectacular displays	2 to 6
Parade grounds	0·2 to 1
Protection of property, patrol and prison work	0·5 to 1·5
Quarries	·5 to 1·5
Railway goods yards, marshalling yards, factory yards, etc.	0·25 to 1
Road making and repairing	1 to 2
Skating	0·5 to 1
Storage yards	0·25 to 1

TABLE XXIII

RECOMMENDED AVERAGE FOOT-CANDLE INTENSITIES FOR THE ILLUMINATION OF THE EXTERIOR OF BUILDINGS AND MONUMENTS

MATERIAL OF WHICH BUILDING IS COMPOSED	INTENSITY OF SURROUNDING ILLUMINATION		
	Bright	Medium	Dark
White or cream terracotta Selected grey Portland stone Selected Chilmark and Tisbury limestone Natural ferro-concrete	6	4	3
Grey Portland stone Selected Bath, or Beer, stone Buff artificial stone Light buff terracotta Faced fireclay brick	10	8	5
Dark Suffolk white brick Silver-grey facing brick Yellow stock brick	16	12	8
Selected Mansfield Red sandstone Light red terracotta	20	16	10

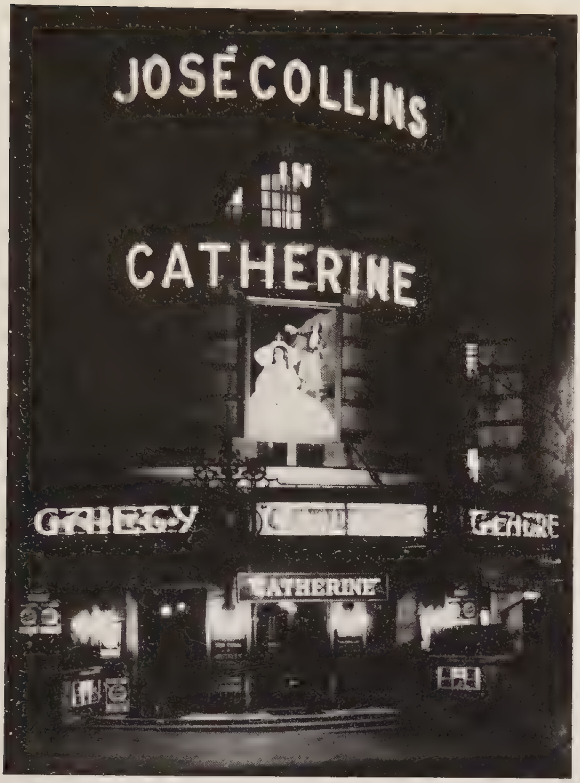

FIG. 217.—THE LARGE PICTURE SHOWN IS ILLUMINATED BY FLOODLIGHTS MOUNTED ON THE PROJECTING VERANDAH.

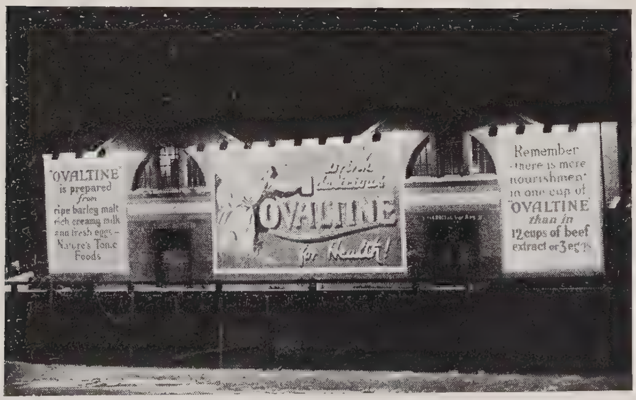

FIG. 218.—SHOWING THE APPLICATION OF THE SPECIAL HOARDING FLOODLIGHTS ILLUSTRATED IN FIG. 198.

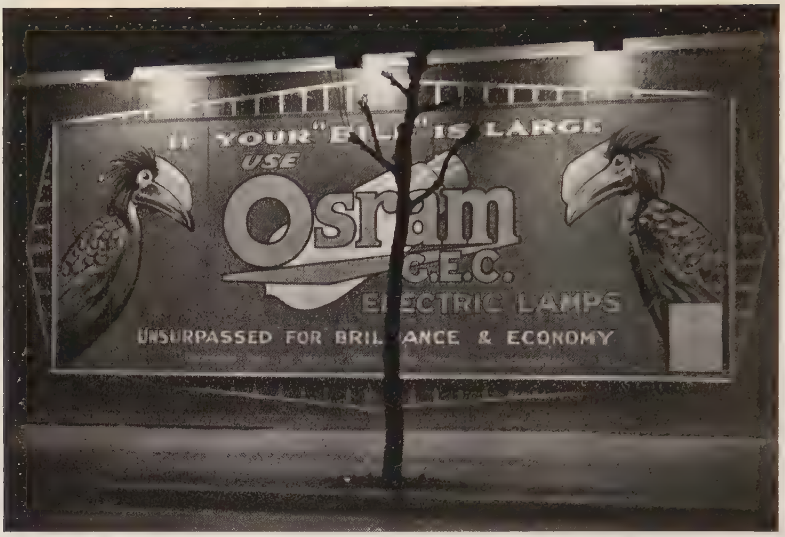

Fig. 219.—Showing Another Application of the special Hoarding Floodlights illustrated in Fig. 198.

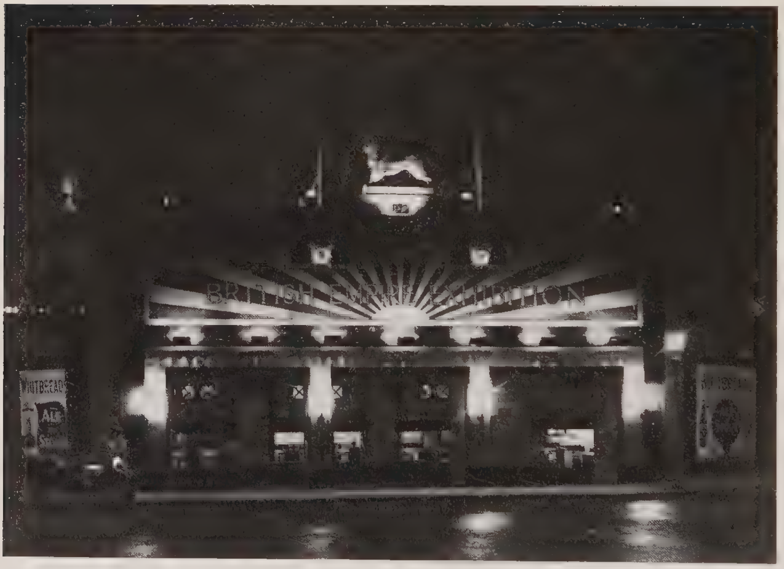

Fig. 220.—The North Gate, British Empire Exhibition. An example illustrating the floodlighting of signs, etc., by projectors fixed immediately below them.

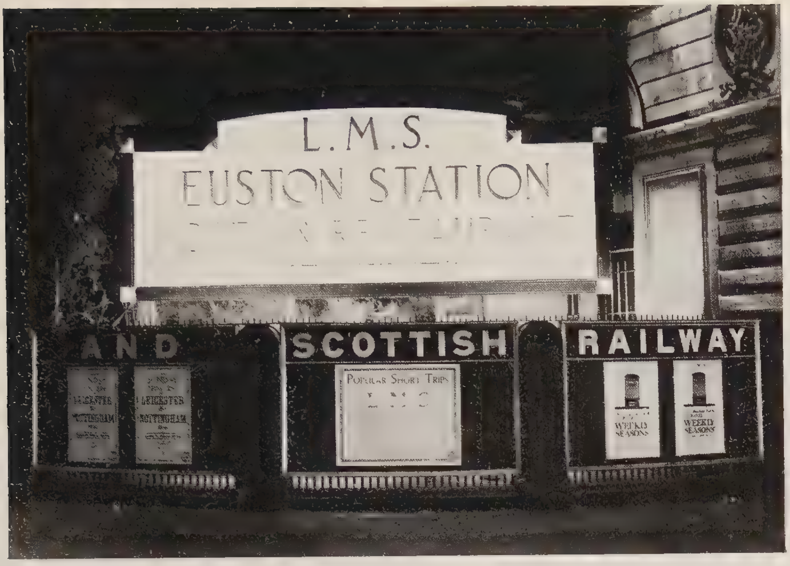

FIG. 221.—ILLUSTRATING THE FLOODLIGHTING OF RAILWAY SIGNS.

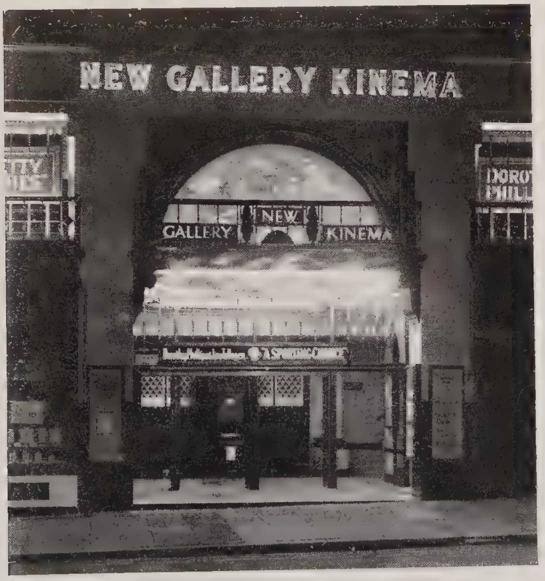

FIG. 222.—FLOODLIGHTING OF THE DOME AT THE ENTRANCE TO THE NEW GALLERY KINEMA.

Buildings constructed of dark red sandstone, common dark red brick, or materials of similar colour, reflect so small a proportion of the incident light that they cannot usually be floodlighted satisfactorily and economically to anything more than a very moderate intensity, and it should not be attempted unless either the surface to be illuminated is comparatively small, or the surroundings are dark and the building is provided with a considerable area of light stone facing. Given such circumstances, a reasonable measure of success can sometimes be obtained, as is evidenced by the illustration shown in Fig. 224. The smoke-begrimed buildings, beautiful though they may be, which constitute so pronounced a feature of certain industrial cities, cannot be dealt with successfully, for the same reason.

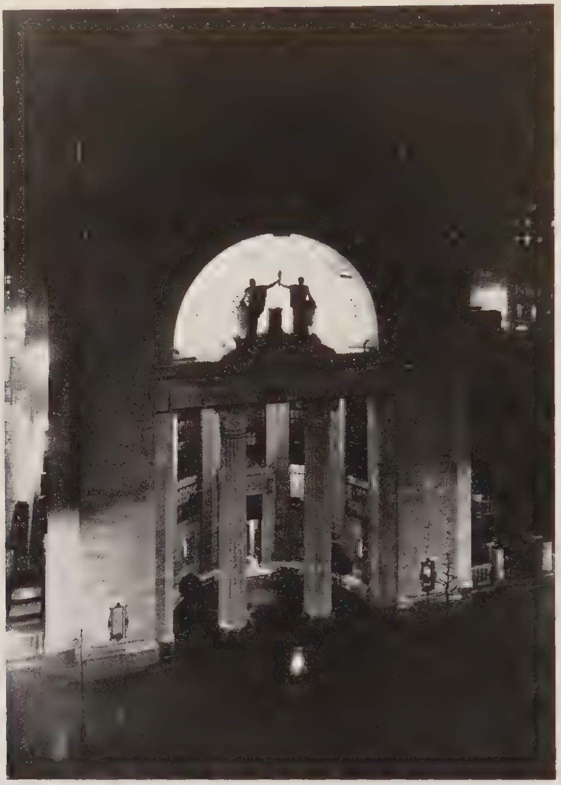

Fig. 223.—In this Example the Group of Statuary appears in Silhouette against the Floodlighted Dome.

Covering Power.—In the solving of floodlighting problems and the designing of installations it is necessary to know the covering power, *i.e.* the dimensions and area of the illuminated field, of any specific projector operating under given conditions, in order that the number required to cover satisfactorily any definite area may be ascertained.

The beam from a circular floodlight is normally conical in form and consequently, if directed upon a surface normal to its axis, illuminates a circular field the area of which, for a beam of given divergence, varies as the square of the distance between the projector and the surface illuminated. If, however, as is usually the case in practice, the projector is inclined so that the beam strikes the surface at an angle, the field produced changes its shape and becomes elliptical; but, provided that the angle of inclination remains unchanged, its *area* still varies as the square of the distance between the projector and the illuminated surface.

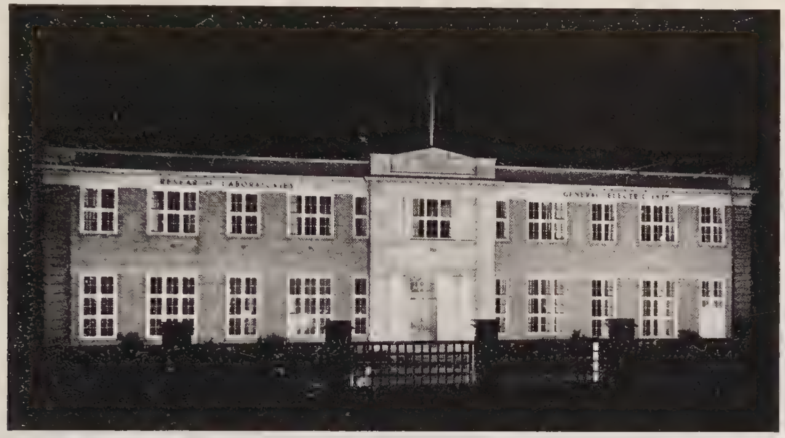

Fig. 224.—An interesting Example of the Floodlighting of a Building of Red Brick. The frontage shown is illuminated by two floods, the beams being crossed.

This property makes possible the compilation of tables calculated for unit distance, from which can be obtained, by simple multiplication, the length, width and area of the illuminated field produced at any distance.

Such a table follows, but, as it is impossible in the space available to deal with all angles of divergence and inclination, only those most generally useful are included therein. For the guidance of those desirous of compiling similar tables to suit individual requirements the formulæ for their construction are given.

In Fig. 225—

Let P represent the light source.
2B represent the angle of the beam in degrees.

ϕ represent the angle between the axis of the beam and the horizontal plane PB.
D represent the distance between P and the vertical plane AB to be illuminated.
L represent the length of the illuminated surface on the vertical plane AB.
W represent the width of the illuminated surface on the vertical plane AB.
A represent the area of the illuminated surface on the vertical plane AB.

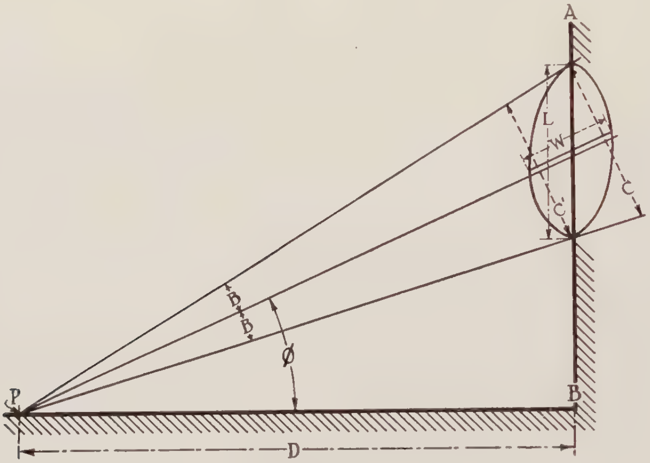

FIG. 225.

Then by simple geometry

$$L = D\{\tan(\phi + B) - \tan(\phi - B)\}.$$

C and C′ are lines drawn from the extremities of L at right angles to the axis of the beam.

$$W = \sqrt{CC'}, \text{ which is identical with}$$

$$W = D\left\{\frac{2\sin B}{\sqrt{\cos(\phi + B)\cos(\phi - B)}}\right\}$$

$$A = \frac{\pi}{4}WL.$$

It will thus be seen that if D is made equal to unity, L and W can be found for all values of D by the simple process of multiplying by D, and A by multiplying by D^2.

TABLE XXIV

COVERING POWER OF FLOODLIGHTS

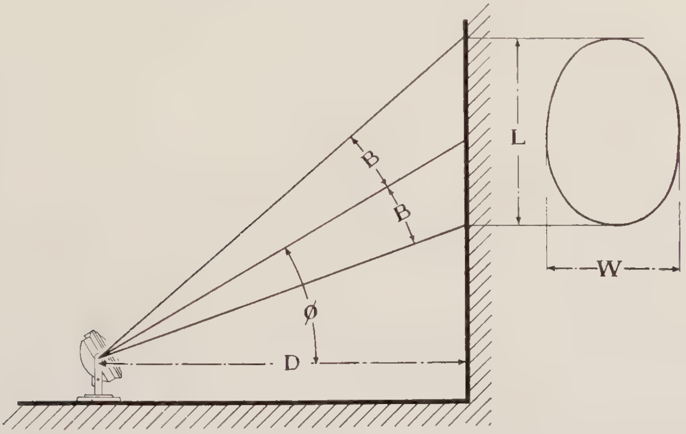

Fig. 225*a*.

Throughout the following tables, D=unity.

To ascertain length and width of illuminated field for any value of D, multiply figures in columns L and W in tables by D.

To ascertain area of illuminated field, multiply figures in column A in tables by D^2.

Divergence of Beam (B+B)=8°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·1398	0·1398	0·0154
15°	0·1499	0·1448	0·0176
30°	0·1868	0·1616	0·0237
45°	0·2811	0·1983	0·0438
60°	0·5677	0·2818	0·1257
75°	2·2403	0·5597	0·9853

TABLE XXIV—*continued*

COVERING POWER OF FLOODLIGHTS

DIVERGENCE OF BEAM (B+B)=10°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·1750	0·1750	0·0241
15°	0·1876	0·1812	0·0267
30°	0·2339	0·2023	0·0372
45°	0·3526	0·2275	0·0630
60°	0·7163	0·3540	0·1993
75°	2·9238	0·7153	1·6430

DIVERGENCE OF BEAM (B+B)=12°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·2102	0·2102	0·0347
15°	0·2255	0·2177	0·0386
30°	0·2813	0·2432	0·0537
45°	0·4251	0·2989	0·0998
60°	0·8696	0·4276	0·2921
75°	3·7087	0·8829	2·5728

DIVERGENCE OF BEAM (B+B)=16°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·2811	0·2811	0·0621
15°	0·3017	0·2912	0·0690
30°	0·3772	0·3256	0·0965
45°	0·5735	0·4015	0·1809
60°	1·1951	0·5796	0·5442
75°	5·7885	1·2755	5·8012

TABLE XXIV—*continued*

COVERING POWER OF FLOODLIGHTS

Divergence of Beam (B+B)=18°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·3168	0·3168	0·0788
15°	0·3401	0·3282	0·0877
30°	0·4259	0·3673	0·1229
45°	0·6498	0·4537	0·2316
60°	1·3702	0·6588	0·7092
75°	7·2683	1·5173	8·6652

Divergence of Beam (B+B)=20°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·3526	0·3526	0·0977
15°	0·3788	0·3655	0·1039
30°	0·4751	0·4093	0·1528
45°	0·7279	0·5067	0·2898
60°	1·5557	0·7407	0·9053
75°	9·2855	1·8095	13·2020

Divergence of Beam (B+B)=22°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·3888	0·3888	0·1187
15°	0·4178	0·4030	0·1323
30°	0·5249	0·4517	0·1863
45°	0·8080	0·5605	0·3558
60°	1·7538	0·8257	1·1378
75°	12·2503	2·1823	21·0041

TABLE XXIV—*continued*

COVERING POWER OF FLOODLIGHTS

Divergence of Beam (B+B)=44°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·8080	0·8080	0·5130
15°	0·8763	0·8415	0·5794
30°	1·1394	0·9595	0·8590
45°	1·9314	1·2492	1·8957
60°	6·3341	2·2624	11·2590

Divergence of Beam (B+B)=50°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	0·9326	0·9326	0·6834
15°	1·0154	0·9731	0·7763
30°	1·3406	1·1182	1·1178
45°	2·3835	1·4909	2·7921
60°	10·7298	3·1634	26·6690

Divergence of Beam (B+B)=60°

ANGLE OF INCLINATION OF FLOODLIGHT ϕ	FIELD ILLUMINATED		
	Length L	Width W	Area A
0°	1·1546	1·1546	1·0474
15°	1·2679	1·2100	1·2026
30°	1·7320	1·4142	1·9245
45°	3·4641	2·0000	5·4435

Angle of Beam.—The angle of divergence—that is, the extent of the spread—of the beam of light from a floodlight projector depends upon (*a*) the contour of the reflector, (*b*) the distance from the reflector of the light source, and (*c*) the size and shape of the lamp filament.

The strength of the beam is by no means uniform. The candle-power intensity is greatest in the centre and falls rapidly towards the outer edge, and it therefore becomes necessary to differentiate between what may for convenience be termed the total beam, and that portion which is sufficiently intense to be utilized in practical work and which is usually designated the main beam. In Fig. 226 the total beam has an angle of divergence of 60 degrees, whilst that of the main beam is only 20 degrees.

Considerable confusion has existed in the past as to the manner in which the limits of the main beam should be determined. The specification for such a purpose must of necessity be to some extent arbitrary. There is, however, a certain basis on which one can work, in view of the fact that, on a floodlighted area, the light patch appears more or less to terminate where the illumination falls to one-tenth of the maximum. There is little doubt that where the illumination is 50 per cent. of the maximum, the intensity at this point is hardly distinguishable visually from the maximum. This fact rules out for floodlighting purposes the method used in the specification of certain searchlight beam angles, where the 50 per cent. maximum criterion is adopted. In view of these facts, and after careful investigation of such alternative methods as the rate of change of candle-power, and the proportion of lumens in the main beam to the lumens in the total beam, the leading English manufacturers of floodlighting equipment have come to the conclusion that to define the limits of the main beam as the angle at which the illumination produced on a surface normal to its axis falls to 10 per cent. of the maximum value, is a method which is preferable to any other in that it is based on a scientific fact. The practical application of this definition is illustrated in Fig. 227, in which is shown the illumination produced by three different floodlights. It will be seen

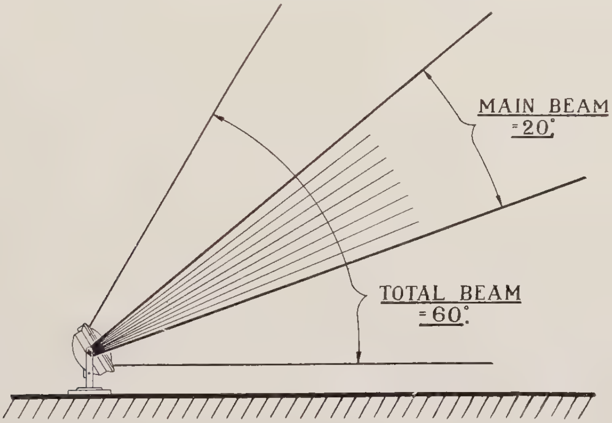

Fig. 226.

that the maximum intensity is, in each case, 8 foot-candles. The limiting intensity, namely, 0·8 foot-candle, occurs at angles of 5, 10, and 15 degrees to the axis, giving main beams of 10, 20, and 30 degrees respectively. In all that follows, the term *beam* refers to the main beam as already defined.

It must not be thought that because the intensity of the beam varies in the ratio of 10 : 1, the illumination on the subject will vary in the same proportion; this is not the case, for the following reasons.

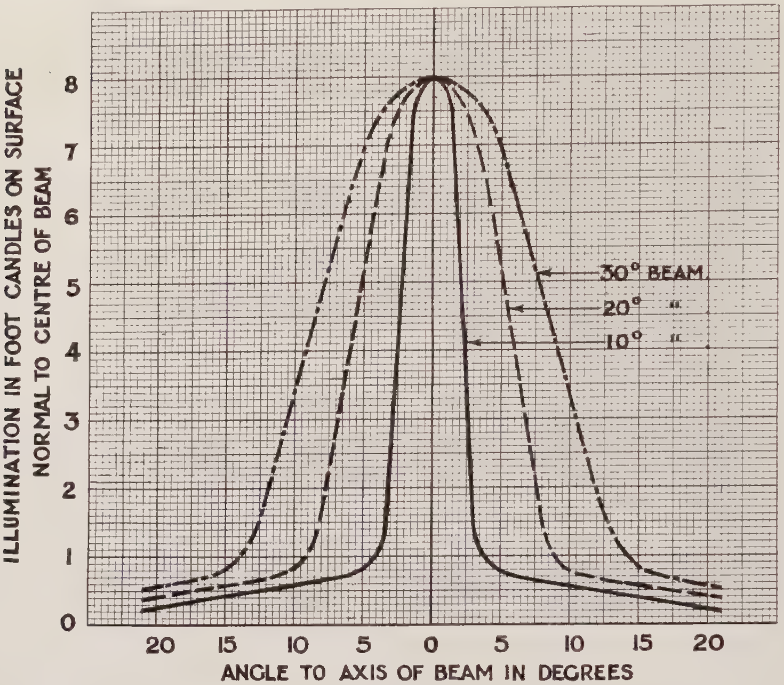

Fig. 227

Referring to the 10-degree beam in Fig. 227, it will be seen that although the illumination falls to one-tenth, or 0·8 foot-candle, at 5 degrees each side of the axis, measurable illumination is produced at much greater angles, 0·25 foot-candle, or $3\frac{1}{8}$ per cent. of the maximum, being shown at no less than 20 degrees from the axis. This, and the fact that if the surface is considerable the beams are overlapped, makes the resultant illumination much more even than might be supposed.

Spill-light and Overlap.—The term spill-light is sometimes applied to the light emitted by a floodlight at angles greater than that comprised in the beam (see Angle of Beam), but is more correctly used to describe the light flux in such portions of the illuminated field as extend beyond, or are spilled over, the boundary of the object or area to be illuminated. Some proportion of the light must inevitably be lost in this way and it is necessary that such should be taken into account when calculating the total light flux, *i.e.* the lumens, required for a specific duty.

In Fig. 228 the rectangle represents the boundary of the surface of an object to be floodlighted, and the five ellipses the illuminated fields produced by the beams of the projectors used. The shaded areas represent portions of the respective fields which are spilled or wasted. The loss due to this cause is happily not so great as might be expected from a comparison of the respective areas, owing to the fact that the intensity, in those parts of the field which are wasted, is usually less than in those which are utilized. The loss depends to some extent upon the outline of the object, but in normal cases, and in well-designed installations, does not usually exceed from 10 to 20 per cent.

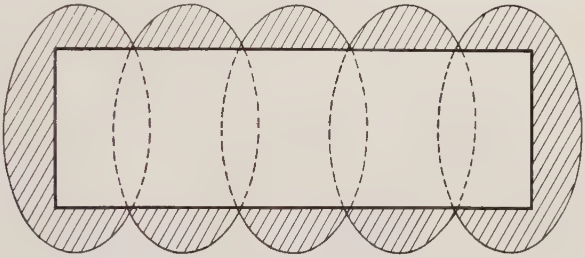

Fig. 228.—Diagrammatic Representation of Spill-light and Overlap.

The overlap—that is to say, the extent to which the illuminated fields must overlap each other in order that the whole of the surface of the object may be covered—is also shown in Fig. 228. The overlapping portions are bounded by the dotted lines. It will be seen that if the overlap is increased the intensity on the surface illuminated will become more even, whilst if it is decreased it will become less even. The limit in this direction is, however, soon reached, as it will be obvious that, if continued, portions of the surface would be left without sufficient illumination.

Beam Efficiency.—The efficiency of any floodlight is represented by the percentage of the total lumen output of the lamp used which is contained in the actual beam. This is known as the beam efficiency, and should take into account all losses, including the absorption of the glass front. It must not be supposed that this represents the total light output of the floodlight, since, as explained when considering angle of beam, such is not by any means the case. It is, however, only the lumens in the actual beam which are of interest to us, and it therefore follows that in considering the practical application of floodlights it is the *beam* efficiency which must be known. Standard equipments are available giving beam efficiencies of from 30 to 60 per cent. The actual value for any specific equipment and lamp can usually be obtained from the manufacturer.

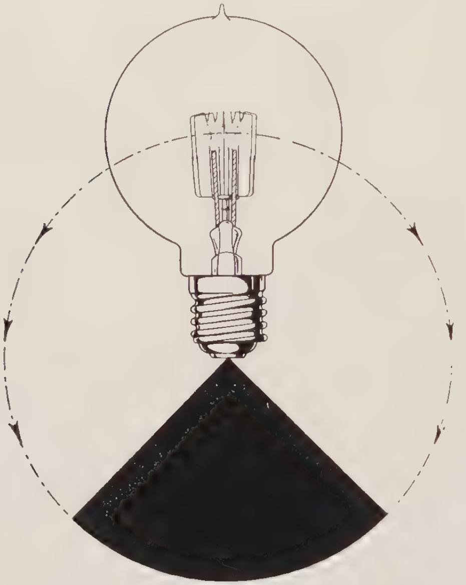

FIG. 229.—PERMISSIBLE TILTING OF CONCENTRATED-FILAMENT FLOODLIGHTING LAMP. THE LAMP MAY BE INCLINED EITHER SIDE OF THE VERTICAL AS INDICATED BY THE ARROWS, BUT THE TILTING MUST NOT BE CONTINUED BEYOND THE COMMENCEMENT OF THE BLACK PORTION.

Lamps.—Whilst almost any type of gas-filled lamp may be used for floodlighting in conjunction with a suitably designed reflector, those normally used are (*a*) the standard gas-filled lamps used for ordinary parallel or series burning, and (*b*) the 250-watt and the 500-watt round-bulb floodlighting lamps in which the filament is specially concentrated. The former, when inserted in the floodlight, hang cap uppermost. The latter are used with the cap downwards, and, owing to their special form, are subject to certain limitations as regards the position in which they can be used. It is important that they should not be tilted downwards to an extent greater than 45 degrees from the vertical. Fig. 229 shows the lamp, cap down. It may be inclined either side of the vertical as indicated by the arrows, but the tilting movement must not be continued beyond the commencement of the black portion. Whenever either standard lamps or floodlighting lamps are required to burn in series they should be specifically ordered ‘ for series burning.’

Whichever type of lamp is used it is necessary to know its output in lumens. The following table gives the output in lumens of ‘ Osram ’ gas-filled lamps of the sizes usually employed for floodlighting.

TABLE XXV.

TABLE XXV

DETAILS AND LUMEN OUTPUT OF 'OSRAM' GAS-FILLED LAMPS FOR FLOODLIGHTING

100-260 VOLTS

Voltage Ranges	Watts	Standard Cap	Approximate Lumen Output
100 to 130	100	B.C.	1300
	150	B.C. or E.S.	2100
	200	E.S.	2810
	300	G.E.S.	4370
	500	G.E.S.	8120
	1000	G.E.S.	17500
	1500	G.E.S.	26300
200 to 260	100	B.C.	1130
	150	B.C. or E.S.	1820
	200	E.S.	2600
	300	G.E.S.	4030
	500	G.E.S.	7280
	1000	G.E.S	16200
	1500	G.E.S.	25400

ROUND-BULB FLOODLIGHTING TYPE

Voltage Ranges	Watts	Standard Cap	Approximate Lumen Output
100 to 130	250	E.S.	3320
	500	G.E.S.	7460
200 to 260	250	E.S.	3140
	500	G.E.S.	6970

Influence of Size and Shape of Lamp Filament.—When considering the question of beam angles, reference was made to the fact that for a given contour of reflector the characteristics of the resultant beam are influenced by the size and shape of the lamp filament. This effect is quite apart from the wattage of the lamp and exists between one standard lamp and another, as distinct from the difference between, for instance, a standard gas-filled lamp and one of the special floodlighting or projection lamps the filament of which is concentrated into a comparatively small area.

The extent to which this variable can influence the performance of the complete unit is strikingly illustrated in Fig. 230. The curves A, B, and C show the illumination, on a plane normal to the axis of the beam and located at a distance of 25 feet, produced by a single floodlight. Each of the lamps used was a standard gas-filled lamp of exactly the same wattage and approximately equal lumen output. Each lamp was in the correct focal position, and the remarkable variation in the resultant beam is attributable solely to the difference in the size and shape of the filament of the respective lamps.

It is obvious that if, in an installation designed on the basis of the utilization of the illumination shown by curve A, the lamps actually used were of either of the types giving the illumination shown by curves B and C, the effect on the object illuminated, which the designer had in mind, could not readily be obtained, and it is therefore particularly important that all installations of floodlighting should be made exactly in accordance with the specification laid down by the illuminating engineer responsible for the design of the installation. These curves also make clear the reason underlying the fact that it is essential that those responsible for the maintenance of floodlighting

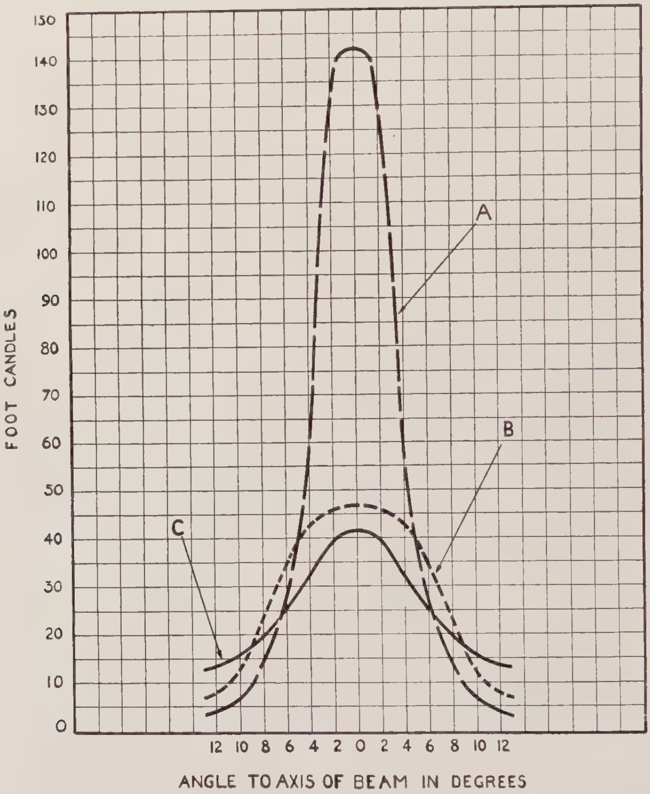

Fig. 230.

installations should either insist that all lamps used for replacements are of precisely the same make, type, wattage, and voltage as those originally installed, or should satisfy themselves that any contemplated change can be made without detriment to the results originally obtained.

Use of Colour.—The introduction of colour in floodlighting is an added weapon in the armoury of the illuminating engineer. Strikingly beautiful as may be the effects obtained by what is becoming known as ordinary floodlighting, they pale into insignificance when compared with those obtained by the illumination of the same object in skilfully blended or suitably contrasting colours. The ability to paint, as it were, with appropriately coloured light the whole or any particular portion of the object which it is desired to beautify, offers endless possibilities.

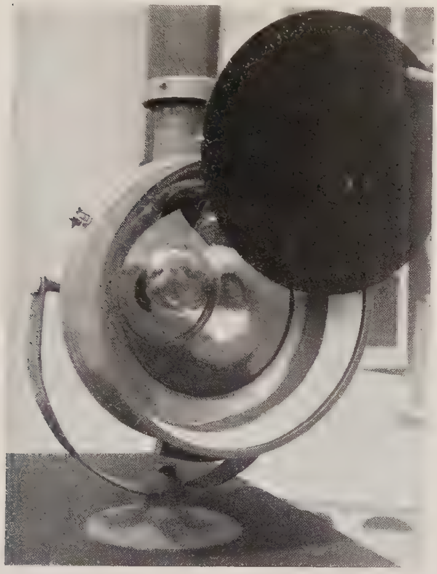

Fig. 231.—Insertion of Colour Screen in Circular Projector.

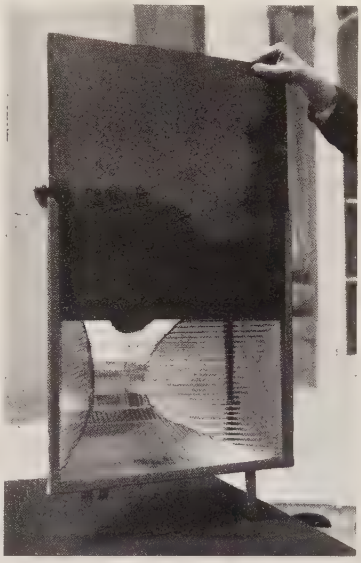

Fig. 232.—Insertion of Colour Screen in Rectangular Projector.

Floodlighting in colour is achieved most satisfactorily by the employment of suitable colour screens, usually of glass, fixed in front of the projectors, and through which the beams pass. Clear lamps are used as in ordinary floodlighting, and the screen is inserted in grooves provided in front of, and some distance from, the clear-glass cover of the projector. For use with projectors equipped with the higher-wattage lamps the screens may advantageously be built up of strips carried in a metal frame. Figs. 231 and 232 show colour screens being placed in position.

The selection of appropriate colours, and the determination of the manner in which they should be combined or contrasted for the securing of a pleasing effect, necessitate the exercise of a colour sense which is all too rare. It may be stated briefly that the softer and more delicate shades of colour are usually the most successful. Yellows in shades from primrose to deep amber, pinks from blush to old rose, and the lighter shades of mauves and greens can all be used with advantage; crude reds and blues, in particular, should be avoided. But the subject as a whole is so complex that it is desirable to approach it with restraint.

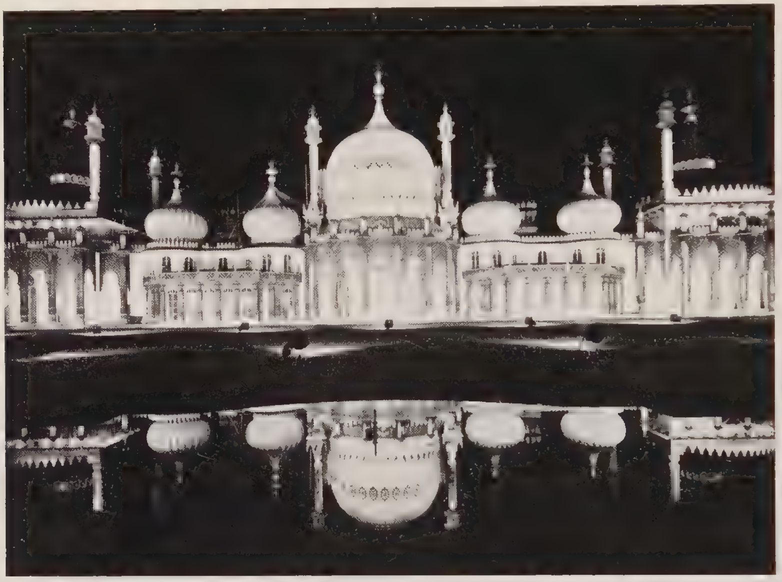

Photo by G. W. King, Brighton.

Fig. 233.—A remarkable Photograph showing the Royal Pavilion, Brighton, Floodlighted in Colour.

A notable installation of this description was the floodlighting in colour of the Royal Pavilion, Brighton, in June 1926. This installation, illustrated in Fig. 233, was referred to in *The Electrician* as ‘one of the finest examples of spectacular floodlighting that has yet been presented.’ The light projected on the domes and minarets was orange-amber, that on the face of the building a delicate shade of green, and that in the arched recesses a golden yellow.

Another example is illustrated in Fig. 182.

Maintenance.—As in all lighting installations, the continued success of any installation of floodlighting depends in large measure on the care exercised in its maintenance. The allowance for depreciation provided in the initial design is intended to cover the diminution in the light output of the lamps throughout their normal life and the accumulation of dust in and upon the equipment during the periods between cleaning. Lamps should always be renewed at the expiration of their normal life, as if retained beyond this period the efficiency of the installation quickly suffers. The whole of the equipment, including the lamps, should be carefully cleaned at appropriate intervals, dependent upon the cleanliness or otherwise of the surrounding atmosphere. In the case of a building or monument, the surface also requires attention, and should be washed down, steam-cleaned, or renewed by sand-blasting at regular but less frequent intervals. Time and labour expended in these directions are always more than repaid.

Calculation of Requirements.—The science of illumination has now reached such a stage that there is no longer any excuse for the promiscuous trial-and-error methods upon which earlier installations of floodlighting were based. Once the fundamental principles are thoroughly grasped, the calculation on the lumen basis of the number of the projectors and the wattage of the lamps required presents no greater difficulty than is experienced in an ordinary installation of interior lighting. An example will make clear the simplicity of the method.

Assume the floodlighting of a large store, constructed of selected grey Portland stone, located in a brightly lighted shopping district. Let the total frontage be 150 feet wide by 80 feet high, and let the display windows and facia sign extend to a height of 20 feet. Let the width of the street be 80 feet, and suppose that the projectors can be fixed conveniently on the opposite side at a height of 30 feet. Let the depreciation factor be 1·5 (depreciation is due to discoloration of the building, ageing of lamps, and the accumulation of dust on the equipment), and make an allowance of 15 per cent. for loss due to spill-light. Let the beam efficiency of the projectors be 35 per cent.

The calculations fall into two parts, the determination of—

(*a*) the required total lumen output of the *lamps*;

(*b*) the number of projectors that will suffice to cover the area.

(*a*) From Table XXIII we find that an intensity of about 6 foot-candles is necessary.

Height of building less windows $=60$ feet.

$\therefore$ Area to be illuminated $=60\times150=9{,}000$ sq. feet.

$\therefore$ Total lumens required on building $=6\times9{,}000=54{,}000$.

Multiplying by depreciation factor and allowing 15 per cent. for spill—

Total required lumen output of projectors

$$=54{,}000\times1{\cdot}5\times1{\cdot}15=93{,}150.$$

$\therefore$ *Total required lumen output of lamps* $=93{,}150\div{\cdot}35=266{,}143.$

(*b*) Consideration of the height of the projectors and the width of the street gives for the inclination of the beam $\tan^{-1} 0{\cdot}25$, *i.e.* 14° 2′.

Having regard to the distance, a medium beam angle, say from 20 to 22 degrees, is obviously called for.

From Table XXIV :—

If $\phi = 15$ degrees, $(B+B) = 22$ degrees, and $D = 1$ foot,

then $L = \cdot 4178$ foot and $W = \cdot 4030$ foot.

$\therefore$ for $D = 80$ feet, $L = 33\cdot 4$ feet, $W = 32\cdot 2$ feet.

To cover a height of 60 feet, vertical columns of 3 fields will be required. Since the combined lengths of three ellipses would be 100·2 feet, this allows 40 feet for overlapping and spill. Allow 10 feet top and bottom for spill and 20 feet for overlapping. To determine the number of such columns it is necessary to know the width of each field where it is cut by the edge of the building. Let this width be W′,

then
$$W' = \frac{W}{L}\sqrt{L^2 - R^2},$$

where R is twice the distance from the centre of the ellipse to the line W′.

In this case
$$W' = \frac{32\cdot 2}{33\cdot 4}\sqrt{(33\cdot 4)^2 - (13\cdot 4)^2}$$
$$= 29\cdot 8 = 30 \text{ feet approximately.}$$

$150 \div 30 = 5$, so that 5 columns would just cover the area; but to give satisfactory illumination at the ends, 6 would be required. Thus the total number of projectors required is 18. The total lumens required from the lamps is 266,143; the required output per lamp is therefore $266{,}143 \div 18 = 14{,}786$. Reference to Table XXV shows that this necessitates the use of 1,000-watt lamps, whose output is 16,200 lumens.

The example dealt with represents a typical floodlighting problem. It may be that in certain cases the solution cannot be arrived at quite so readily, but it will be found that, be the problem what it may, careful application of the methods outlined will invariably enable a satisfactory solution to be reached.

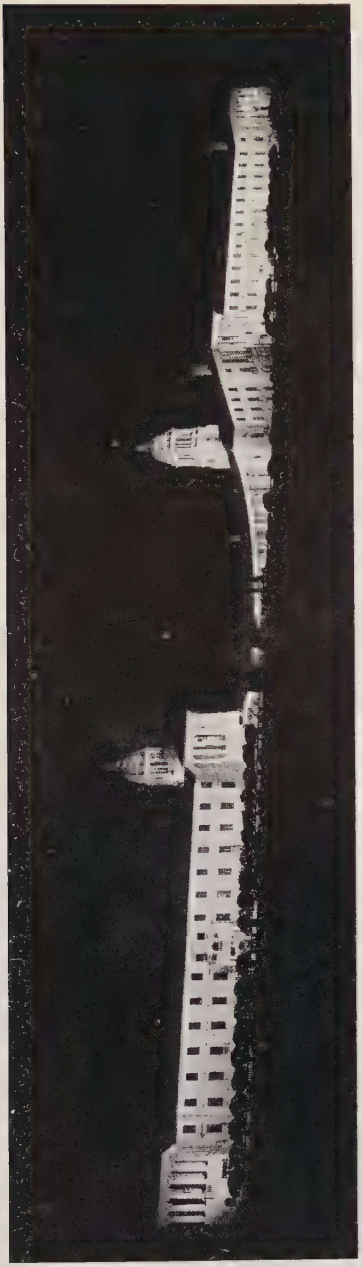

Fig. 234.—Floodlighting of the Union Building, Pretoria.

CHAPTER VIII

DOMESTIC LIGHTING

Essentials of Illumination in the Home—The Entrance—The Dining-Room—The Drawing-Room—The Bedroom—A Special Reading Unit for the Bed—Decorative Lighting—Demonstration Cubicles—Examples of Bad Lighting—Types of Plain, Antique, and Decorative Lighting Units.

Of all things which go to make the home really homelike, light is among the foremost. A home may be pleasantly situated, and no expense spared in its furnishing, yet without good light, light correctly applied, the real home is non-existent. The subject of home lighting has been carefully considered for many years past, the chief object being to design lighting equipment which will not only make the home furnishings more beautiful, but will create that restful atmosphere so essential to real home life.

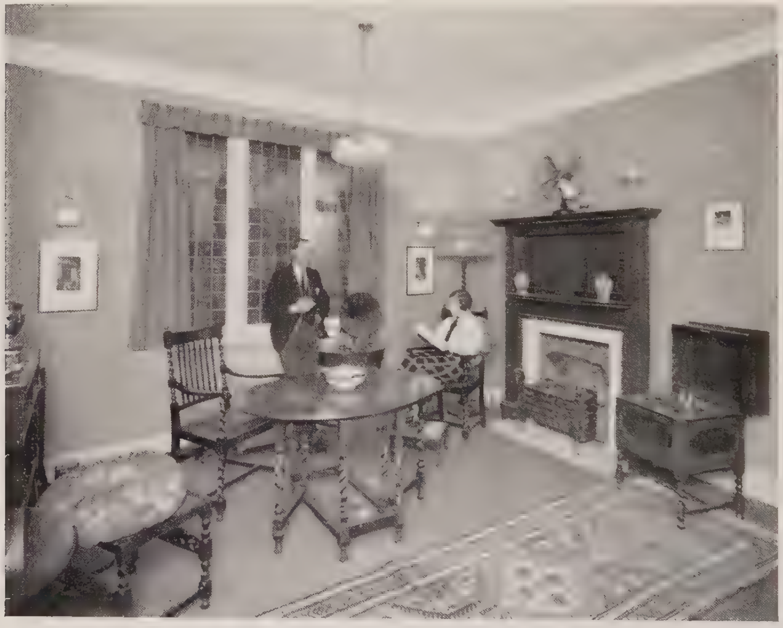

Fig. 235.—This Indirect Unit provides our Illumination.

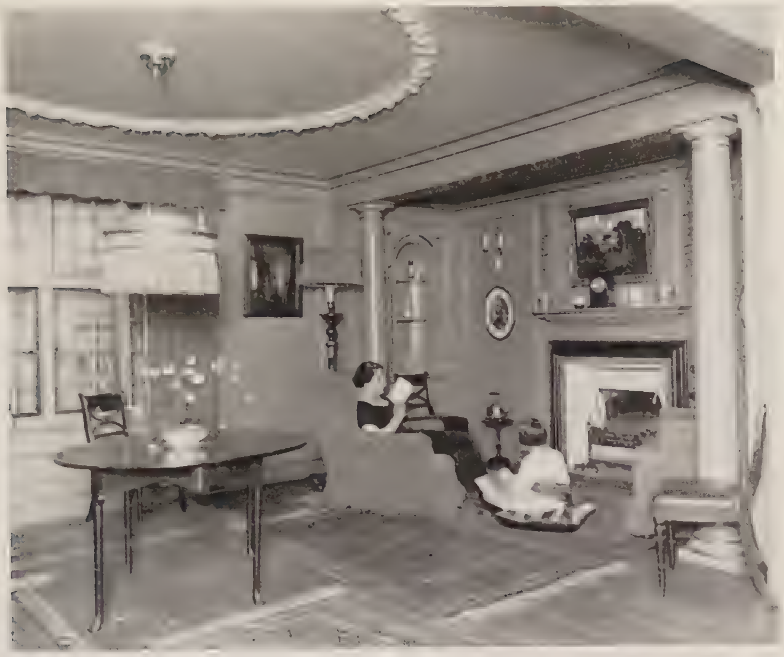

FIG. 236.—THE CENTRAL UNIT EFFECTIVELY ILLUMINATES THE DINING-TABLE.

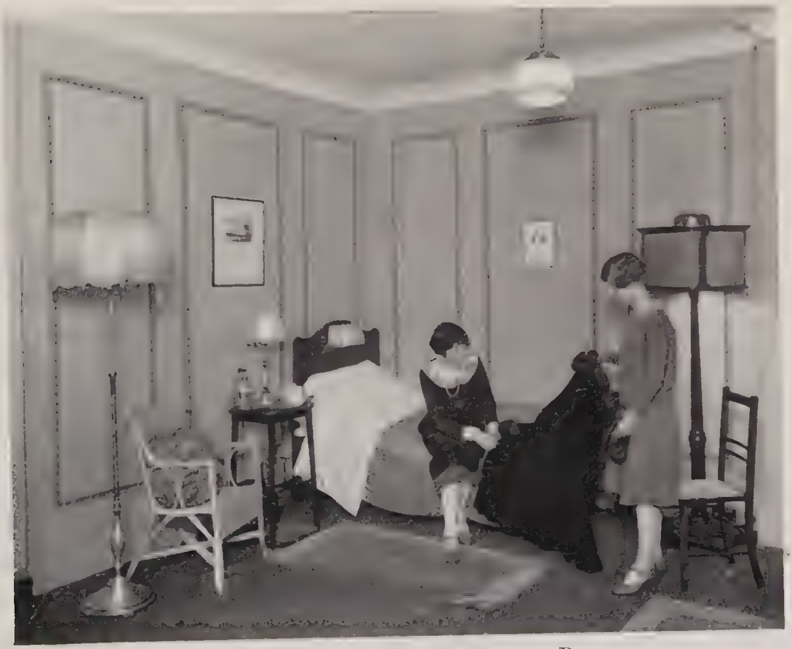

FIG. 237.—NOTE THE UNIT OVER THE BED.

To show the chief essentials of illumination in the home it is not necessary by means of plans to indicate the positions of various fittings, etc. Our purpose will be better served if the most important parts of the average home are illustrated and described.

The entrance to the home is through the hall; the latter should be so illuminated that a pleasant appearance is presented immediately the door is opened. A decorative central fitting, or a floor standard and table lamp, or, if the hall contains a fireplace, a pair of candle fittings over the mantelpiece, will produce a note of welcome. In a large hall a combination of these methods could be installed, thus enabling changes to be carried out.

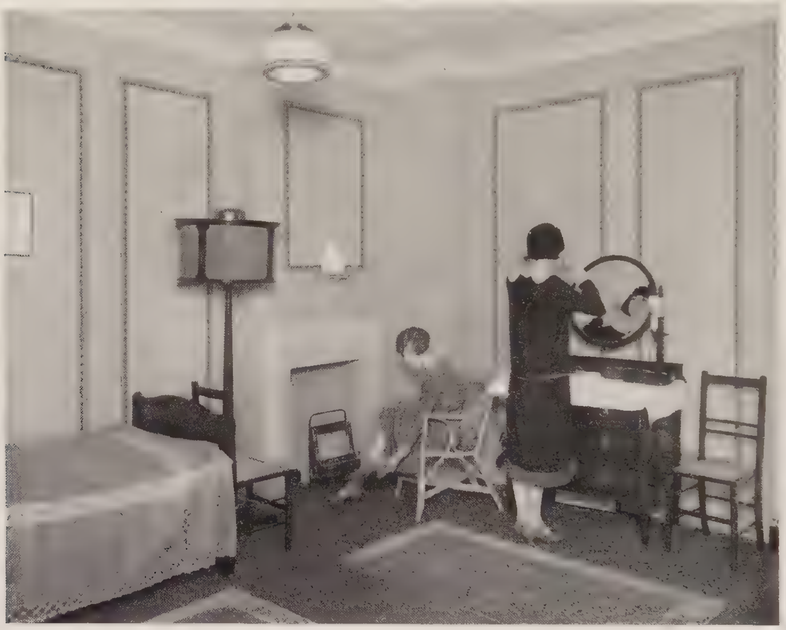

Fig. 238.—Note the Units on the Dressing-Table.

In the drawing-room, Fig. 235, a unit of the semi-indirect type will produce soft, even illumination; note that, in our illustration, the shadows are very soft and do not disguise the furnishings. The Jacobean floor standard is also in keeping with the design of the furniture, a factor to be remembered when purchasing portable lighting units. Note that, at the back of the chair near the floor standard, the latter is obtaining current from a plug and switch fitted on the skirting of the room. This is one of many plugs, an arrangement which makes portable fittings really portable and mobile.

In a large number of electrically lighted rooms the position of the furniture is governed by the position of the lighting units. This is not so in an installation designed upon modern principles; a number of plugs enable portable units to be used in any desired position, thus making for greater home comfort.

Referring again to Fig. 235, it will be seen that a plug is fitted immediately under the table. At the moment our photograph was taken the function of the plug was to supply current to an electrically heated mat; it is quite as useful with a portable table lamp, an arrangement which obviates the necessity for tables being situated near the wall in order to avoid long lengths of flexible leads across the floor.

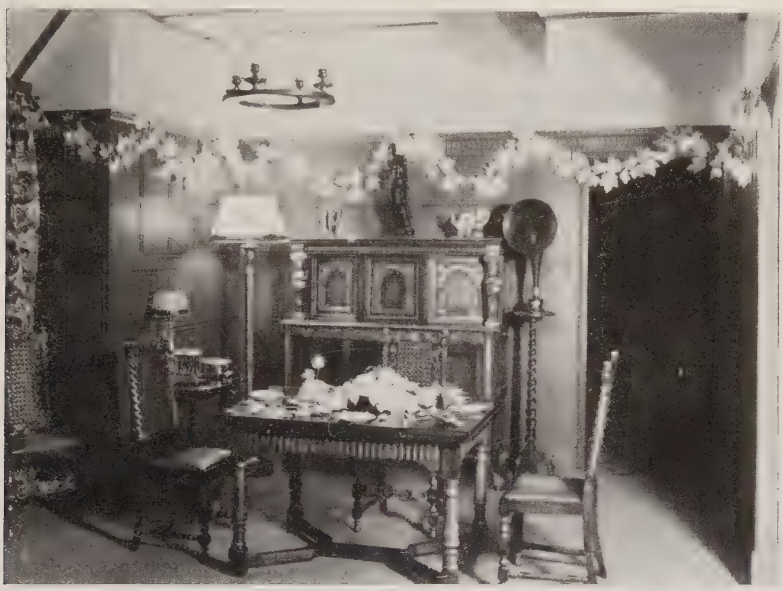

Fig. 239.—Miniature Lamps provide a Charming Decorative Medium at Christmas Time.

On the mantel over the fireplace are fitted two crystal-glass units; these, with the two bracket units fitted over the pictures, make very pleasing and alternative lighting systems.

The essentials of illumination in the dining-room demand a high intensity of light on the table, with soft light of lower intensity on the faces of the diners; these requirements are met in the dining-room illustrated in Fig. 236. The central unit is equipped with three white-sprayed lamps surrounded by a coloured silk shade which harmonizes with the general colour scheme of the room. The white-sprayed lamps provide an abundance of light upon the table, and light of a lower intensity is filtered through the silk shade. The lamp

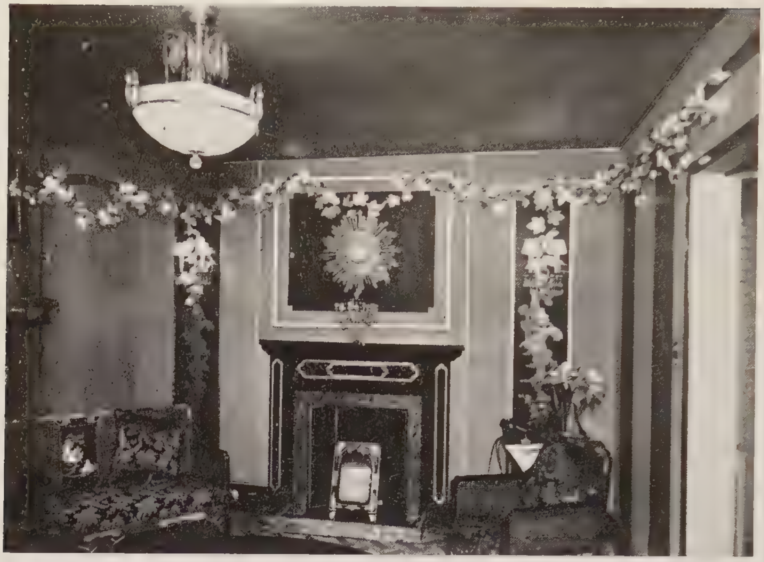

Fig. 240.—The Electric Lighting Fixtures here are of Oriental Design.

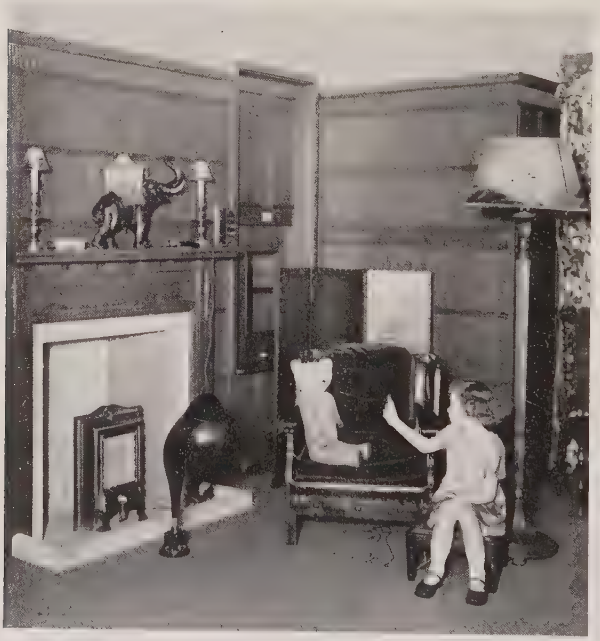

Fig. 241.—One Corner of a Dining-room converted into an Attractive Nursery with the aid of suitable Electric Lighting Units.

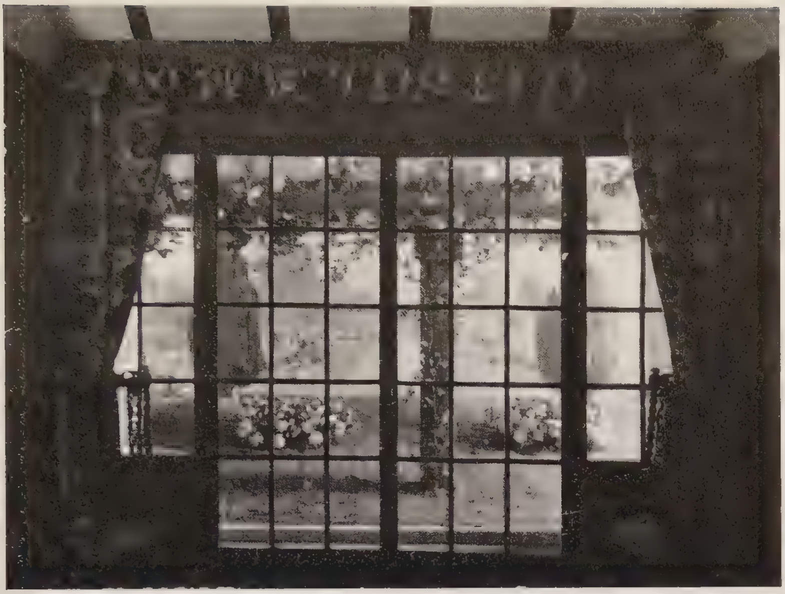

FIG. 242.—THIS SHOWS HOW ELECTRIC LIGHT CREATES THE ILLUSION OF ARTIFICIAL SUNLIGHT.

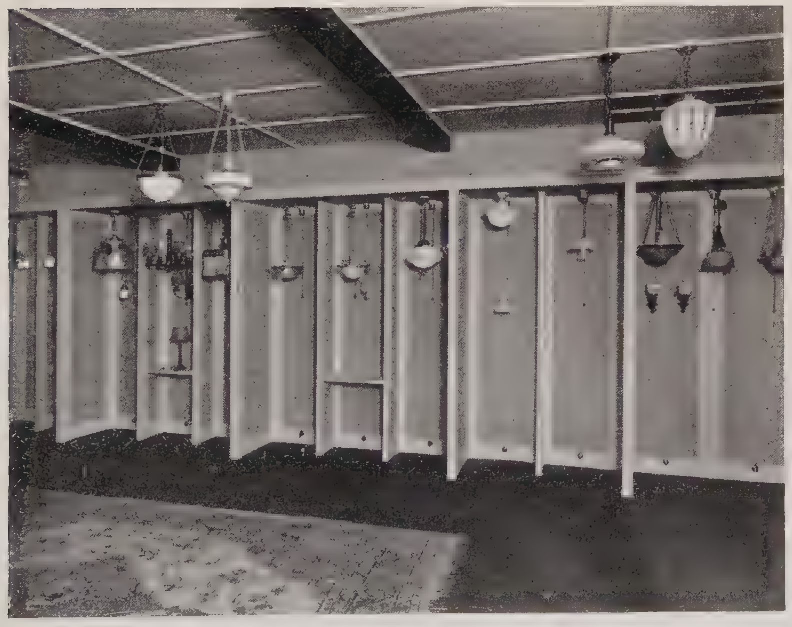

FIG. 243.—THIS DEMONSTRATION ROOM ENABLES THE 'EFFECT' OF GOOD AND BAD LIGHTING UNITS TO BE SEEN.

filaments cannot be seen, as is the case when clear gas-filled lamps are used.

In this room is also fitted a pair of candle fittings of the bracket type; these provide a decorative and useful feature—the latter because, on certain occasions, the light from these units alone will be found to be adequate and desirable. The floor standard, in the centre of the illustration, is perfectly mobile from the fact that a number of wall plugs are fitted round the room.

We have two illustrations of a bedroom, Figs. 237 and 238; these photographs were taken to show the effect of different types of lighting units. The central fitting, which is extremely decorative, is of the semi-indirect type; the light from it is well diffused, thus obviating any undesirable shadows. In Fig. 237 one of the floor standards and the table lamp are of the same design, and are quite in harmony with the decorative features of the panelling. The unit over the bed, which allows reading in comfort, was designed to harmonize with the general furnishing scheme. It will be seen that in this room two distinct systems of lighting can be used: general lighting from the central

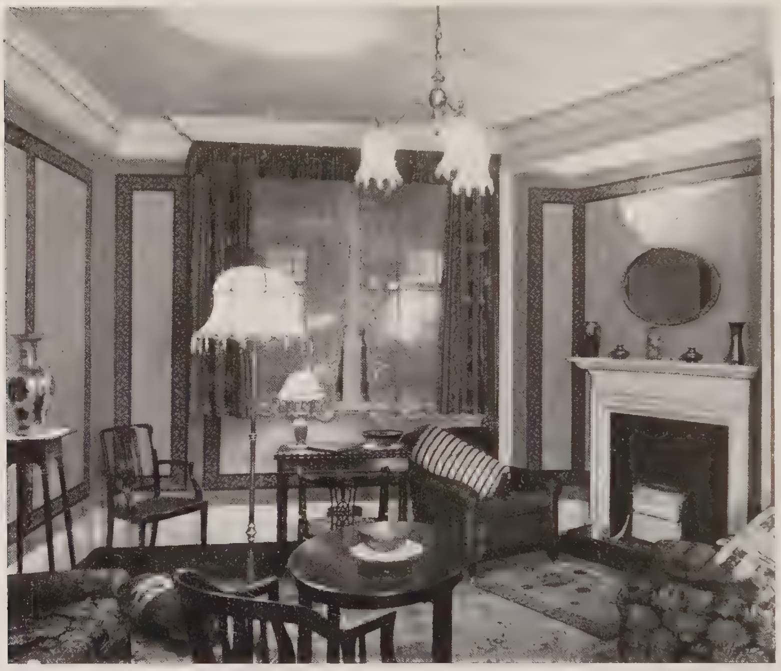

Fig. 244.—An Example of Bad Lighting. Note the patches on ceilings and walls.

unit, or local lighting from floor standard and table lamp. Here, again, a number of wall plugs make the lighting units perfectly mobile, so that the bed and furniture may be moved to any desired position.

In Fig. 239 is illustrated a dining-room of quite a different type; our photograph was taken at Christmas time, which accounts for the presence of the special illuminated decorations. In this room the central unit is in the form of a four-light candle fitting of antique design; this is fitted well above the heads of the diners, and it provides good general illumination.

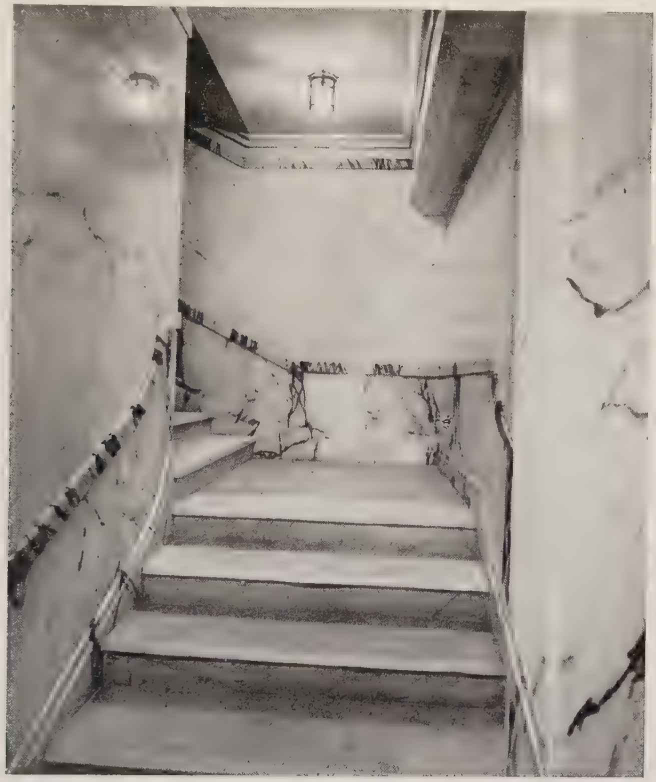

Fig. 245.—An Unsuitable Staircase Unit. Note the reflections.

This illumination is supplemented as desired by the floor standard, which is a specially designed double unit; soft light is afforded by lamps fitted inside the shade, or alternative illumination is provided from lamps and a special reflector concealed in the top of the unit. This is a form of lighting most suitable for low rooms, the whole of the indirect light being reflected from the white ceiling.

The drawing-room illustrated in Fig. 240 is decorated in Oriental style; this demonstrates how beautifully modern electrical equipment can harmonize with the most unusual style of furnishing. The colour scheme is black and gold, and it gains new beauty from the electric-light fittings. Round the walls are fitted a number of candle brackets in gilt and crystal. In the centre is a pendant with shade, which, like those of the brackets, is of silk, hand-painted in Oriental fashion.

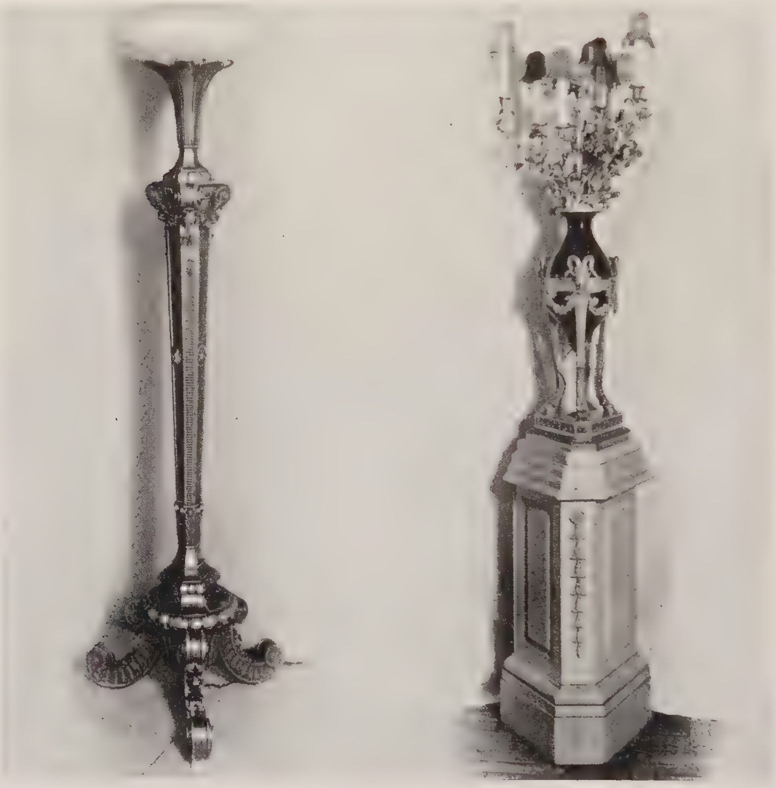

FIG. 246.—ORNATE STANDARD UNITS ARE PLEASING IN ANY HALL.

The centre fitting permits very charming effects, to be obtained by switching on coloured light or white light as occasion demands. Additional illumination is afforded by a black-and-gold lacquer floor standard, also fitted with a suitably painted silk shade.

A pleasantly illuminated corner of a dining-room will at all times substitute for a nursery *pro tem.*; such a corner is illustrated in Fig. 241. Here, light from a floor standard and two candle fittings provides abundant and glareless illumination. A special feature of the lighting scheme is the howdah on the back of the elephant; this is really a

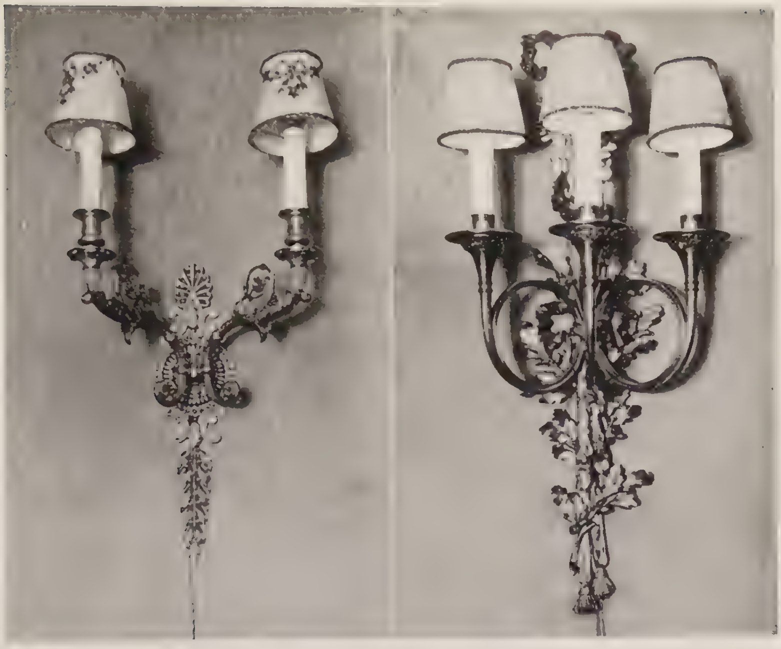

FIG. 247.—CANDLE BRACKETS GIVE 'TONE' TO A WALL OR PANEL.

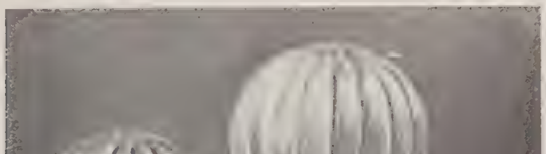

FIG. 248.—AN ALTERNATIVE SUGGESTION FOR A HALL.

decorative lighting unit composed of a silk shade and a low-wattage lamp. When illuminated the effect is charming, especially to the younger generation.

A special feature in home lighting (which is not, however, of general application) is illustrated in Fig. 242. In certain cases windows look out on to undesirable aspects; electric lighting will go far to make these aspects more pleasant. The garden illustrated is artificial, and it has been constructed in a small space between the window and the wall; on the wall is a painted sheet which, with the artificial garden, creates the illusion of the grounds of a large country mansion. To make the illusion more complete, two lighting units are fitted out of sight; these provide artificial sunlight and moonlight respectively.

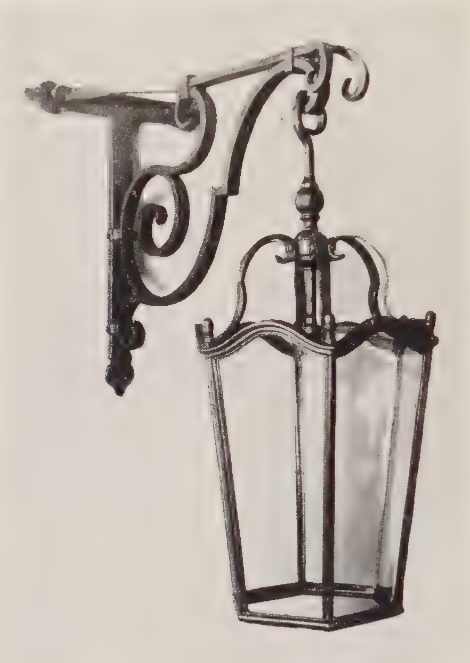

Fig. 249.—Antique Pattern Bracket Lantern.
This is suitable for old-fashioned houses.

Regarding the remainder of the lighting units in the home, it may be said that bare lamps should be avoided in all positions; diffusing units in the kitchen, bathrooms, and on landings will give every satisfaction. All electrical contractors should, in order that their customers may discriminate between good and bad units, erect a few demonstration cubicles similar to those illustrated in Fig. 243.

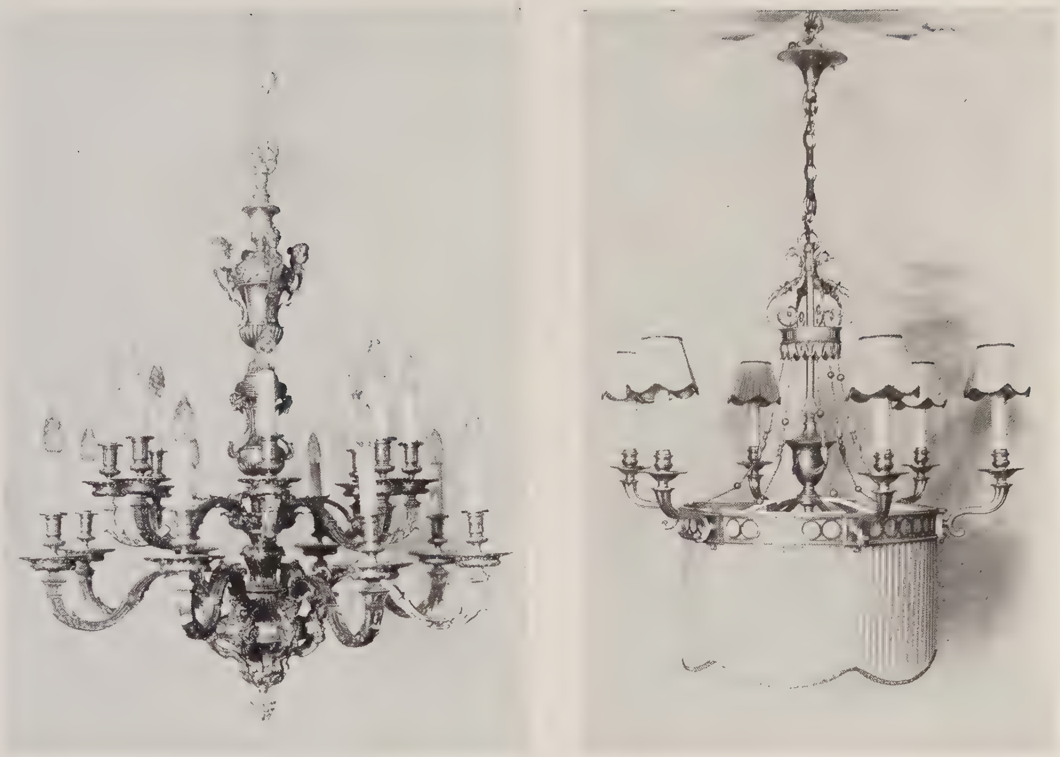

Fig. 250.—Two Different Styles of Candelabra for the Dining-room. Both are of period design, and should harmonize with the general furnishing.

CHAPTER IX

PUBLIC BUILDINGS, PLEASURE GARDENS, AND SEASIDE RESORTS

The B.M.A. Building—Special Lighting Units—The Balcony—The President's Platform—The Council Chamber—Special Lighting Units—The Committee Room—Islington Town Hall—Main Entrance Hall—The Balcony—The Council Chamber—The Sitting-Room—The Canadian Government Building—Main Entrance Hall—Staircase Units—The Waiting-Room—Unique Lighting Units—Calverley Gardens, Tunbridge Wells—Hove Gardens, Brighton—An Illuminated Garden, the British Empire Exhibition—'Canada,' the British Empire Exhibition—The Casino, Blackpool—Blackpool Town Hall—Blackpool Pleasure-Grounds—An Illuminated Gondola—Collinson's—Pier and Pavilion, Southend.

Referring to the lighting of public buildings in general, one can almost assert that no two buildings contain units exactly alike. The chief reason for this is that public buildings are considered to be important, so that when the electric-lighting installation is being considered the

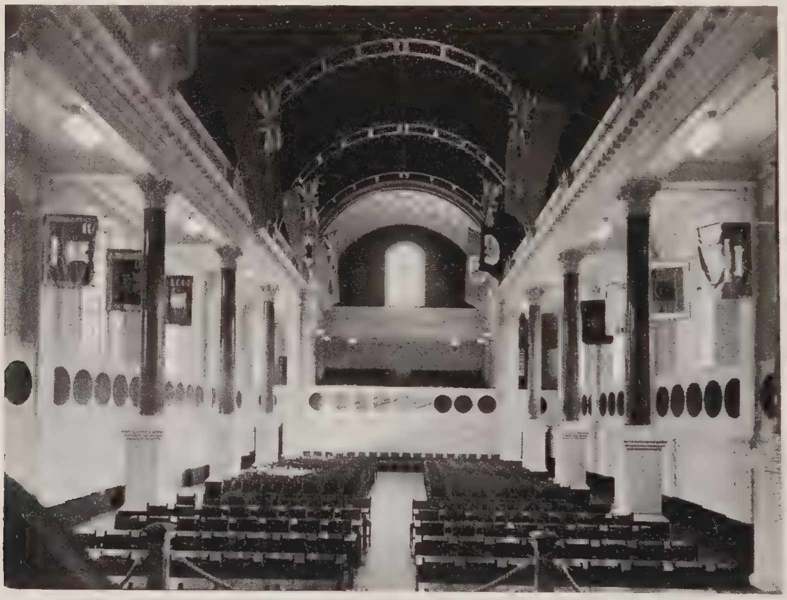

Fig. 251.—The Great Hall, B.M.A. Building. Note the balcony and side lighting units.

general demand is for something 'original.' It is therefore impossible to lay down any different rules for the selection and location of units for this class of installation beyond saying that the lighting equipment should completely harmonize with the architectural features. Under these circumstances we cannot do better than illustrate and describe three of the most recent installations in different types of public buildings. The buildings are: the British Medical Association Building, Russell Square, London; the Islington Town Hall; and the Canadian Government Building, Trafalgar Square, London.

The British Medical Association Building.—This building and the lighting installation were designed by Sir Edwin Lutyens. In this installation the aim which Sir Edwin achieved was 'illumination without glare.'

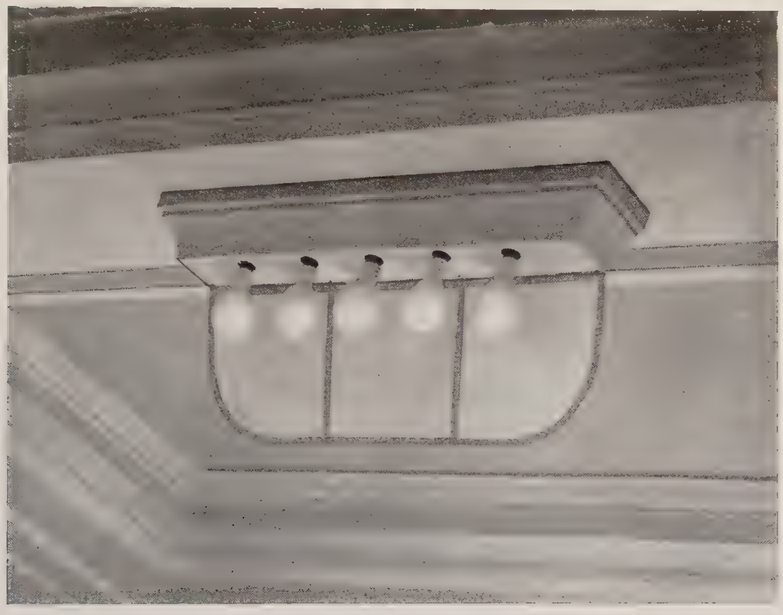

Fig. 252.—Close-up View of Hall Unit.

In the Great Hall, illustrated in Fig. 251, are installed a number of specially designed units; these are to be seen situated between the pillars in an inverted position. Full details of the unit can be seen in Fig. 252. It consists of a white base block fitted with five lampholders recessed below the surface; the latter accommodate white-sprayed lamps. At the back of the block is fitted a light frame covered with light material with a matte surface and a high reflection factor; the frame acts as a reflector. Consideration of the unit will serve to show that the light delivered into the hall is direct diffused light and reflected diffused light. Such illumination is absolutely devoid of glare.

At the far end of the Great Hall is a balcony, a section of which is illustrated in Fig. 253. Round the walls of the balcony are fitted six bracket units, also of special design; one of these units is illustrated in detail in Fig. 254. In design the bracket is square; thus it harmonizes with the square lines of the interior. It is surmounted by an inverted reflector which accommodates a white-sprayed lamp. In this way three kinds of diffused light are obtained :

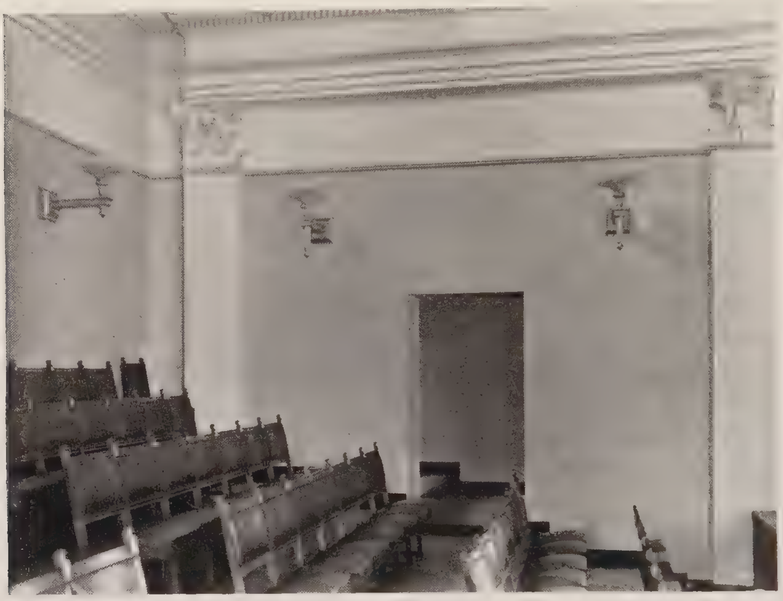

Fig. 253.—Balcony, showing Type and Disposition of Units.

1. Direct light in an upward direction from the lamp.
2. Reflected light in an upward direction.
3. Light through the reflector in a downward direction.

The reflection factor of the walls and ceilings is high, so that the balcony is flooded with light from all directions which is almost shadowless.

At the opposite end of the Great Hall are a platform and a chair used by the President of the British Medical Association. The platform is illuminated through the medium of special standard units, which are more or less concealed by massive pillars; two of the units are illustrated in Fig. 255. In addition, a number of trough reflectors

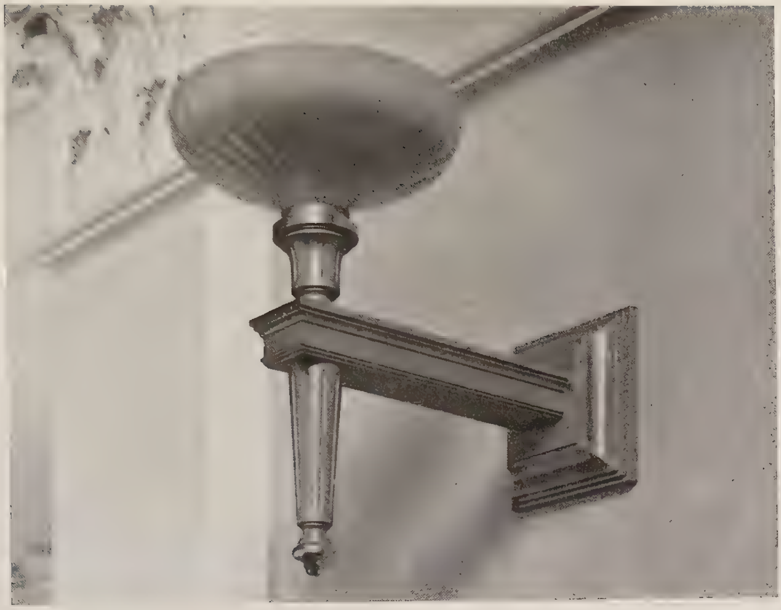

Fig. 254.—A Balcony Unit.

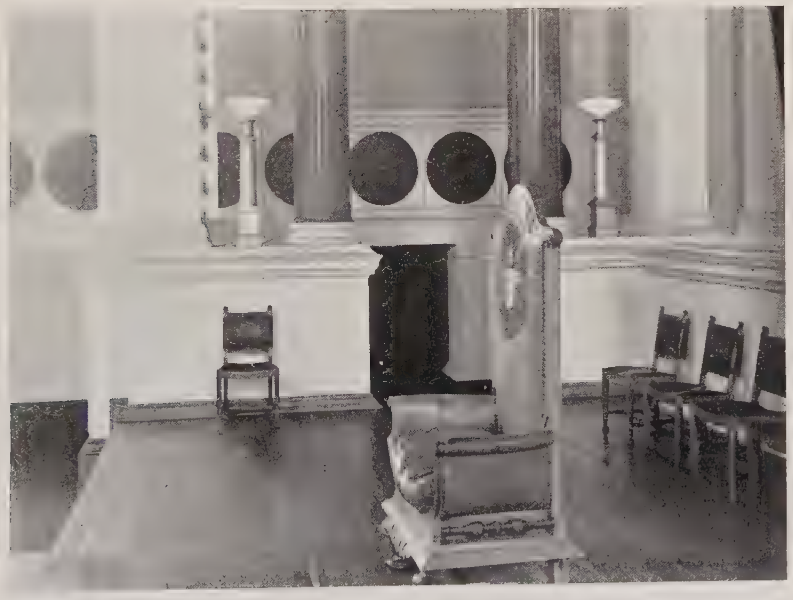

Fig. 255.—The Units which provide Platform Illumination.

are concealed behind the massive columns at the front and sides of the platform. Each reflector accommodates three white-sprayed lamps; two of the reflectors can be seen in our illustration, on the left of the first standard unit.

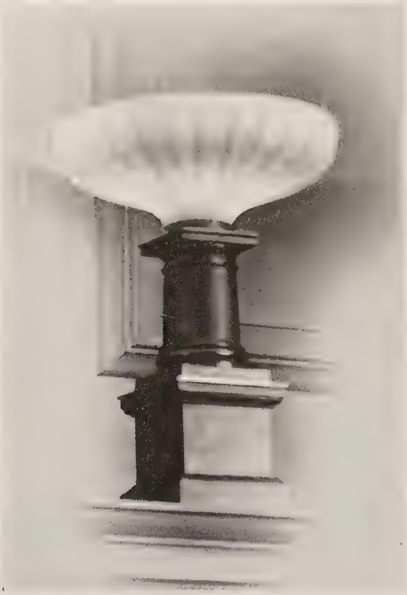

Fig. 256.—One of the Council Chamber Units.

Similar units to the standard units, but much shorter, are fitted in the Council Chamber; one of these units is illustrated in Fig. 256. It is on record that a number of doctors sat in the Council Chamber for some hours for the express purpose of determining the effect of the light upon the eye. The unanimous verdict was that the illumination was excellent, and it was stated that in no case was the discomfort of eye-strain experienced. This is an indication that this installation is ideal for its purpose.

In Fig. 257 is illustrated the interior of one of the committee-rooms in the British Medical Association Building; a day photograph was taken so that the lighting units could be clearly seen. Note the symmetrical spacing and the pleasing contour of the units. Units of this type are exceptionally suitable for this kind of installation; they are shallow and flat, so that a large proportion of the light is projected downwards.

Islington Town Hall.—The chief civic building of a municipality is designed upon lines of extreme dignity; the design of the lighting installation should therefore follow the same lines. There are very few town-hall lighting installations in which the lighting units harmonize with the general architectural features; the reason for this is that the majority of the buildings have stood for the best part of a century, and in the early days of electric light, gas was discarded and gas fittings were wired for electric light. These monuments of inefficiency are still in existence, and the civic fathers are reluctant to see their passing. It is to be hoped, however, that the spadework which is being done in the cause of better lighting will result in the removal of these hideous and harmful installations, and that modern systems of lighting will be installed which will be more in keeping with the importance of the buildings.

As a model of town-hall lighting we illustrate the installation in the recently opened Islington Town Hall; this building is entirely new, and when the lighting equipment was selected adequate consideration was given to the design of units.

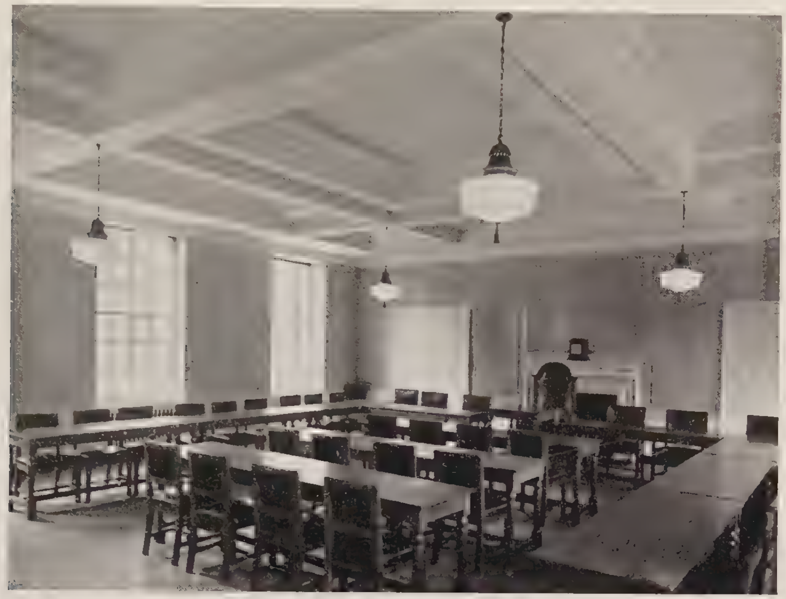

Fig. 257.—Ideal Lighting Units in the Committee-room.

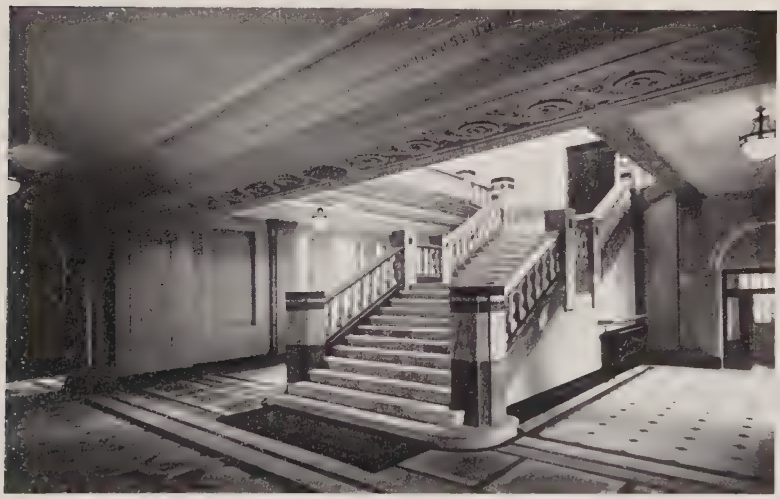

Fig. 258.—Main Entrance Hall, Islington Town Hall.

The main entrance hall, illustrated in Fig. 258, is constructed of white grained marble, and is an excellent example of dignified architecture. The massive staircase, ornate pillars, and decorated ceiling are shown to advantage when viewed under electric light. The units illustrated are of the semi-indirect type, the opal bowls being located in specially designed galleries. Symmetrical spacing is adopted, and the units are fitted close to the ceiling owing to the latter being rather low.

When glancing at this illustration it is at first difficult to see the source of illumination for the staircase; when one mounts the staircase, however, the four units illustrated in Fig. 259 can be seen. These units illuminate not only the stairs but also a balcony. The type and spacing of these units should be noted; it will be seen that, no matter from which angle they are viewed, the general design is such that it follows the general lines of the interior.

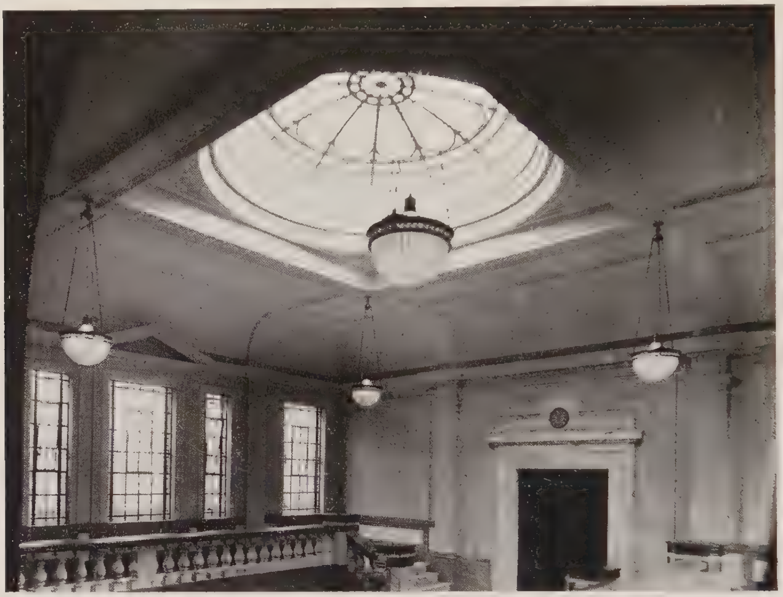

FIG. 259.—STAIRCASE AND BALCONY LIGHTING UNITS.

The unit in the Council Chamber, illustrated in Fig. 260, is in contrast with the remainder. It is a central unit, and after consideration of the lay-out of the chamber it will be seen that it meets every requirement both from an architectural and an illumination point of view. In design the unit consists of a central indirect unit which is surrounded by ten smaller units; the latter are fitted by means of brackets to a massive band. The complete unit is mounted fairly high, but, even so, the total diameter of the unit is such that councillors sitting in the outside row of seats are receiving their quota of well-diffused light.

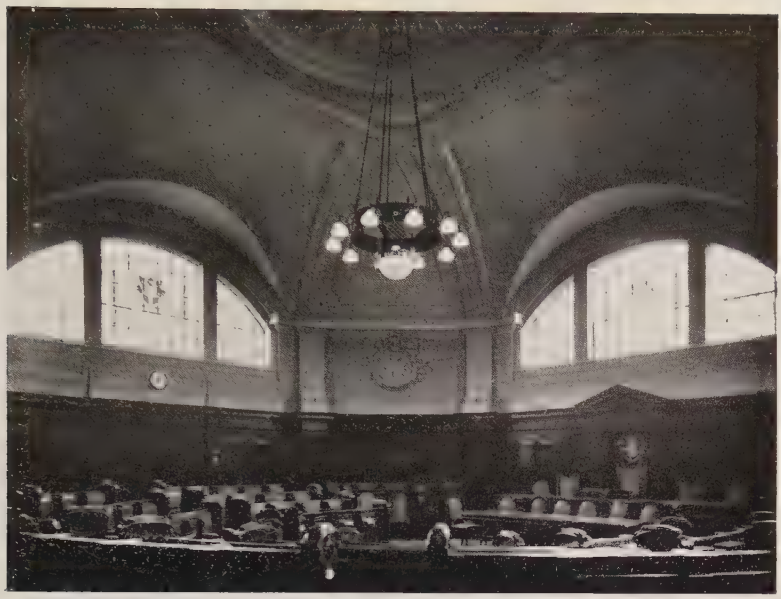

Fig. 260.—The Council Chamber. This picture illustrates what is meant by electric-light fixtures harmonizing with architectural features.

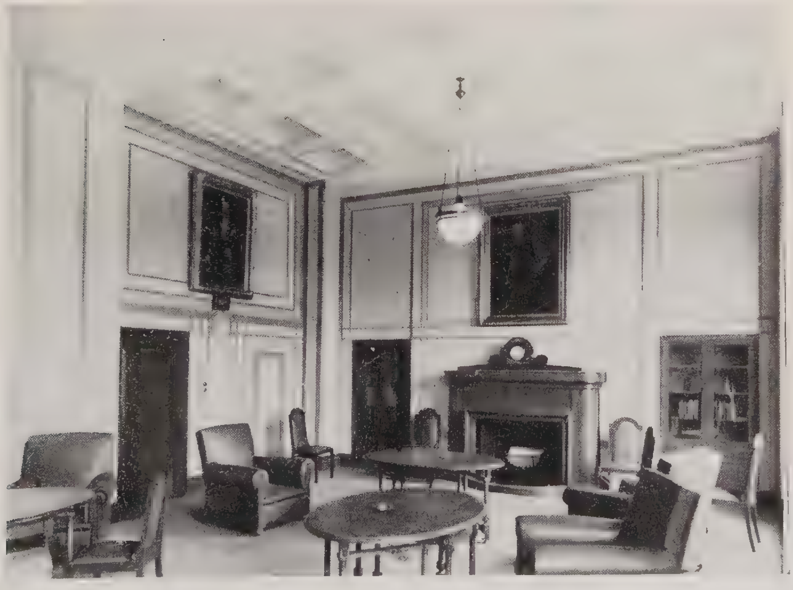

Fig. 261.—The Sitting-room.

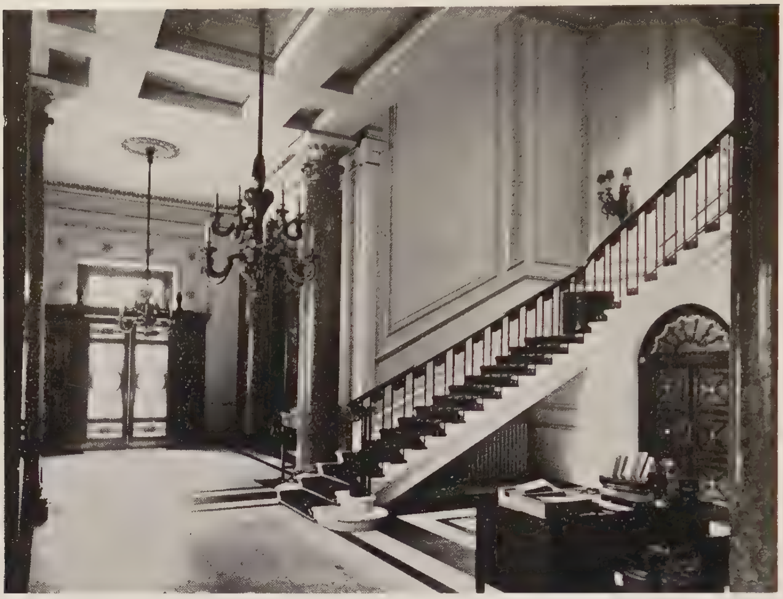

Fig. 262.—Main Entrance Hall and Staircase, Canadian Government Building.

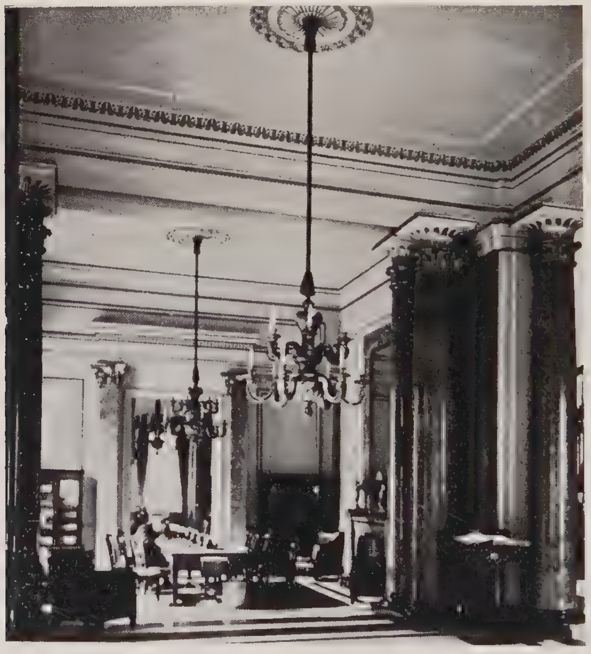

Fig. 263.—Waiting-room.

The interior of the sitting-room in this town hall is illustrated in Fig. 261; our illustration shows one lighting unit, although two are installed, the other one being in the section of the room from which our photograph was taken. The position and height of the unit should be noted, because it is most suitable for this class of interior.

The Canadian Government Building.—The Canadian Government Building is one of the most imposing structures in Trafalgar Square, London; the lighting installation is quite in keeping with the building. Immediately the building is entered one is impressed by the magnificent electric-light fixtures. Two of the fixtures, situated in the main entrance hall, are illustrated in Fig. 262. These are massive 12-light candelabra units in two tiers, with six candle fittings in each tier. The upper tier is smaller than the lower one; this feature, however, does not detract from its massive appearance, and rather adds to its decorative properties.

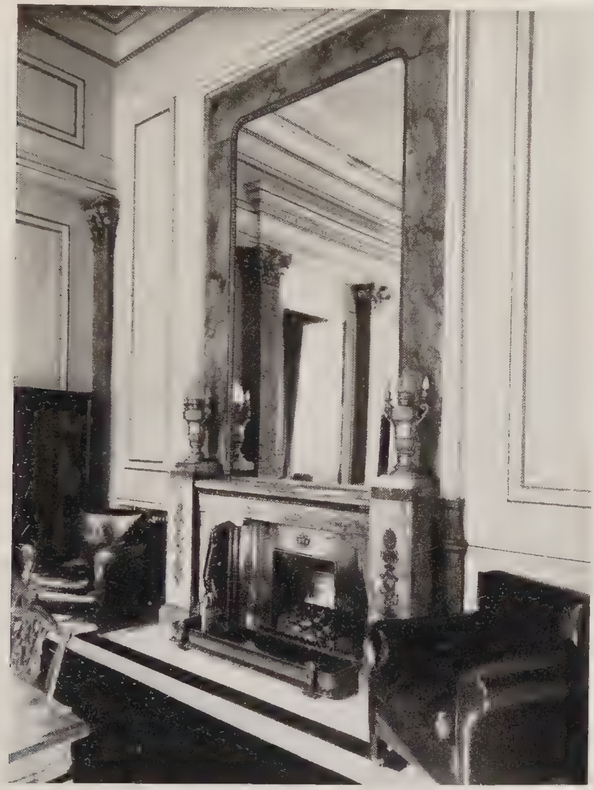

Fig. 264.—Special Mantelpiece Lighting Units.

On the staircase, to be seen to the right of the illustration, is fitted a 3-light candle-bracket unit. At the point where the bracket is located, the staircase turns sharply to the right; the height and design of the unit are such that both portions of the stairs are evenly illuminated, and the lamp filaments cannot be seen in either direction.

A waiting-room in this building is illustrated in Fig. 263. Here are installed two massive candle fittings of similar design to those in the main entrance hall. The method adopted in the suspension of these units can be clearly seen. The units themselves are made of wood gilded and painted; the chains with which they are secured to the ceiling (and the flexible cord which conducts current to the lamps) are concealed in a huge silk cord. This type of unit quite harmonizes with the ceiling decorations and the decorative features of the tops of the columns.

A special feature in this building is the unique lighting units which adorn the mantelpieces over the fireplaces; two of these units are illustrated in Fig. 264. The units are designed in the form of vases, and on the top is fitted a lamp and a shade of the flambeau type; on each handle is fitted a small candle-lamp with a frosted bulb. The units are extremely decorative, and add the final touch to the fireplace ornamentations.

One of the chief attractions of a pleasure-garden or seaside resort is its night-time illuminations. Even in the old days a fête or garden-party was doomed to failure if no arrangements were made to illuminate the most important parts of the grounds with coloured light. Hence we saw multi-coloured glass containers, dear to us as fairy lamps, each accommodating a piece of candle about one inch in length. This method of illumination was by no means certain, especially in windy or wet weather.

The advent of electricity for lighting purposes eliminated the uncertainty of pleasure-ground illumination, and from its present extensive use it is clear that municipalities vie with each other in the application of coloured light in order that their pleasure-gardens and beaches shall be as attractive as possible. Modern light sources in the shape of colour-sprayed lamps are an excellent decorative medium; this touch of colour can be seen and appreciated during daytime as well as night, and it goes far to make a pleasure-resort popular.

One of the most recent applications of coloured lighting to pleasure-grounds is to be seen in the Calverley Gardens at Tunbridge Wells; these gardens in daylight and at night-time are illustrated in Figs. 265 and 266 respectively. The gardens are used chiefly for band concerts, and therefore the bandstand is the centre of attraction. It is octagonal in shape, and opposite sides are outlined with colour-sprayed lamps of the same colour; the colours are amber, red, green, and blue.

Opposite the bandstand are the refreshment-rooms, built on old-

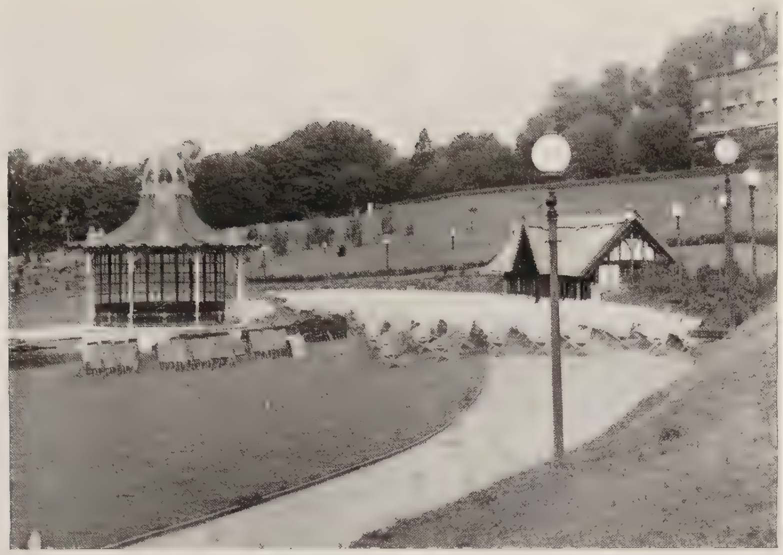

Fig. 265.—Calverley Gardens, Tunbridge Wells (Day).

Fig. 266. Calverley Gardens, Tunbridge Wells (Night).

fashioned lines, even to the attractive thatched roof. The whole of the building and roof is outlined with colour-sprayed lamps of four colours, these being the same as are used on the bandstand.

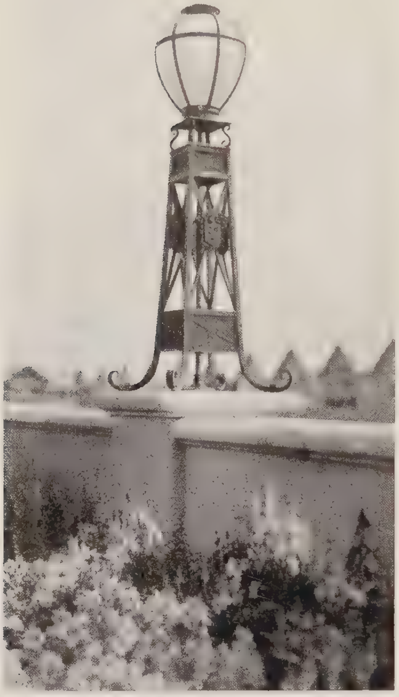

Fig. 267.—A Decorative Lighting Unit to be seen at Brighton.

Another decorative feature in these gardens is the installation of a number of lighting units of the standard pattern. The standards are surmounted by a large diffusing glass globe; when illuminated, the intensity of light upon the paths is sufficient to enable easy passage about the grounds, and it does not detract from the effect of the coloured illuminations.

Another type of decorative lighting unit for the illumination of pleasure-grounds is illustrated in Fig. 267; this is one of the units recently installed to add to the attractiveness of the Hove Gardens at Brighton. Appreciated as its decorative features are during the daytime, it is at night-time that it is seen at its best.

The opal globe on the top of the standard contains a number of colour-sprayed lamps; these distribute beams of coloured light over the gardens in their vicinity, and the effect upon the various-coloured flowers is charming.

An entirely different method of illumination is illustrated in Fig. 268, which portrays a portion of a garden in the British Empire Exhibition of 1925. At the end of this garden was situated a tree in the branches of which were fitted some unique lighting units; the units were in the form of birds, frogs, fruit, etc. Each unit contained a clear or colour-sprayed lamp, so that, apart from their spectacular shapes, the different-coloured light provided very pleasant contrasts.

In Fig. 269 we illustrate another decorative feature which was to be seen at the British Empire Exhibition of 1925; this is the floodlighting of Canada in red and green light. We believe that this is the only photograph taken of Canada which shows the night-time beauty of this magnificent building.

To produce these effects a large number of floodlights were fitted on the grass round the building at a certain distance from it. These were of special design, the object being to obtain a broad distribution of light. The projectors were situated in pairs, and were equipped with a red or green colour-screen. The red projectors were connected to one circuit and the greens to another, and both circuits were connected to dimmers. When the latter were operated the whole face of the building was bathed in red or green light of various intensities. The reflections in the water are from a number of the units described.

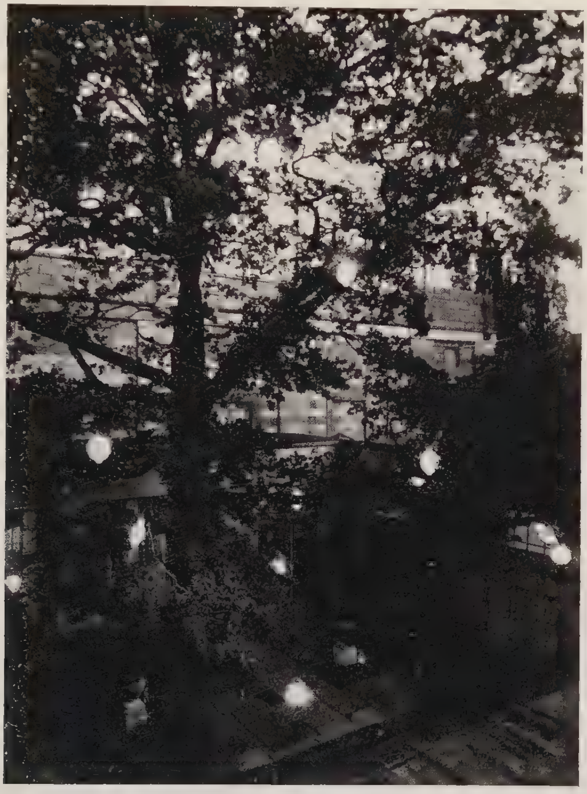

Fig. 268.—An Illuminated Tree and Garden, the British Empire Exhibition.

Regarding the illumination of seaside resorts it should be mentioned that, up to the moment of writing, the most extensive use of colour is being practised at Blackpool. One of the most prominent buildings in this well-known resort is the Casino; day and night photographs of this building are illustrated in Figs. 270 and 271. On this building many thousands of colour-sprayed lamps are used; not only is the building outlined in colour, but the whole of the architectural lines are emphasized. The natural colour of the building is white, so that the day-time effect of thousands of *points* of different colours can be realized. At night-time the effect of the coloured light is more marked because, instead of a coloured point, each lamp is surrounded by a halo of its own colour.

Blackpool Town Hall is to be admired at night-time because of the exploitation of colour; this hall is illustrated in Fig. 272. The windows are outlined with lamps of various colours, a pleasing contrast to the many designs which adorn the building. The Union Jack is very effective in red, white, and blue, and the stars show to advantage in amber. Over the entrance a huge crown in appropriate colours is a distinct and pleasing decorative feature.

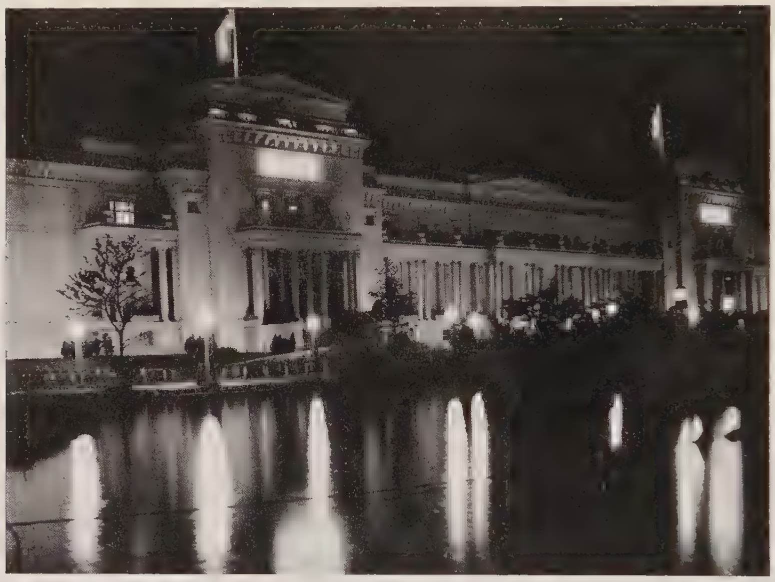

Fig. 269.—'Canada,' the British Empire Exhibition, 1925.

In Fig. 273 is illustrated a night-time view of the pleasure-grounds; in this illustration are to be seen the scenic railway, big wheel, a monster ark, and other places of amusement. The general method of illumination is to outline the structures with various-coloured lamps.

A special illuminated feature at Blackpool was the result of an accident. A mishap occurred to a tramcar, and it was decided to turn it to some use; it was therefore converted into a gondola, and its driver and conductor were dressed as gondoliers. Day and night photographs of the gondola and gondoliers are illustrated in Figs. 274 and 275 respectively. Many hundreds of colour-sprayed lamps are used in the outlining of the boat, and in its journeys round the town it

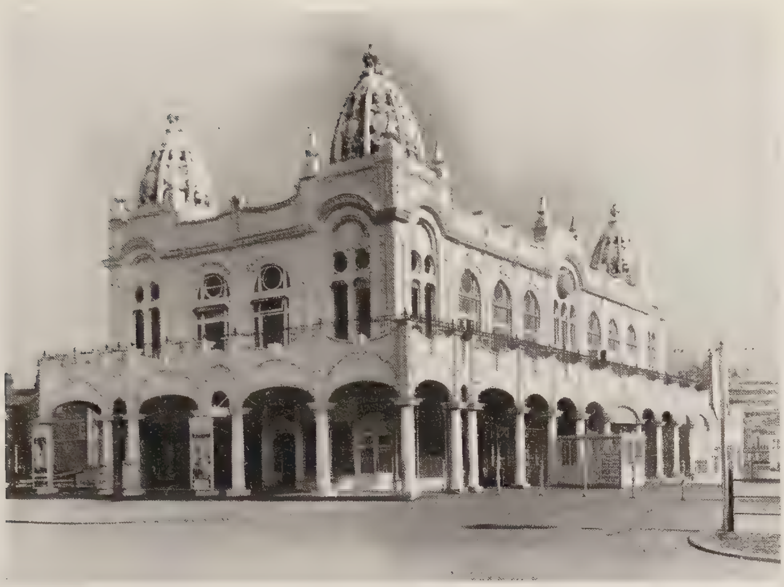

FIG. 270.—THE CASINO, BLACKPOOL (DAY).

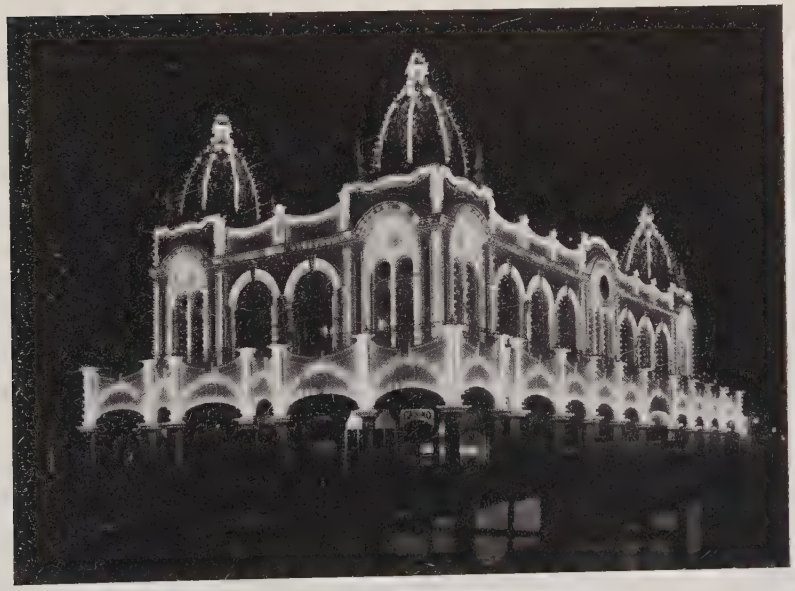

FIG. 271.—THE CASINO, BLACKPOOL (NIGHT).

attracts considerable attention and adds in no small measure to the holiday spirit.

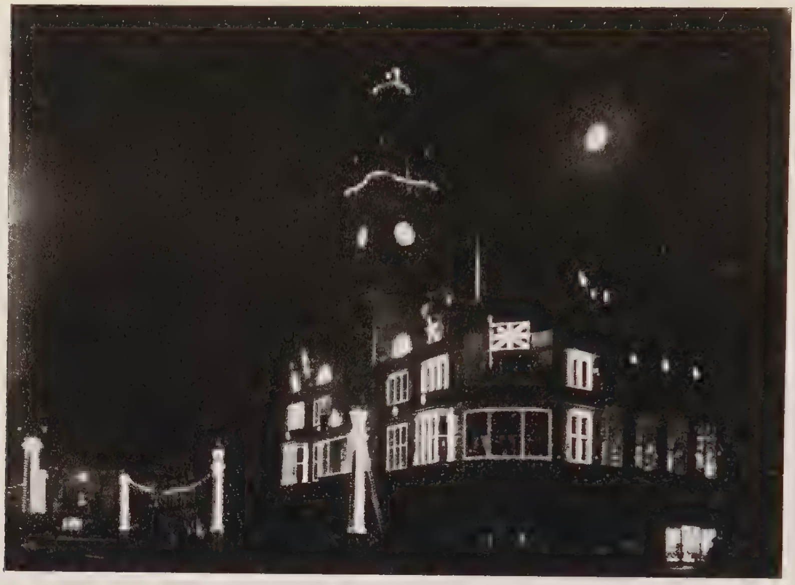

Fig. 272.—Blackpool Town Hall.

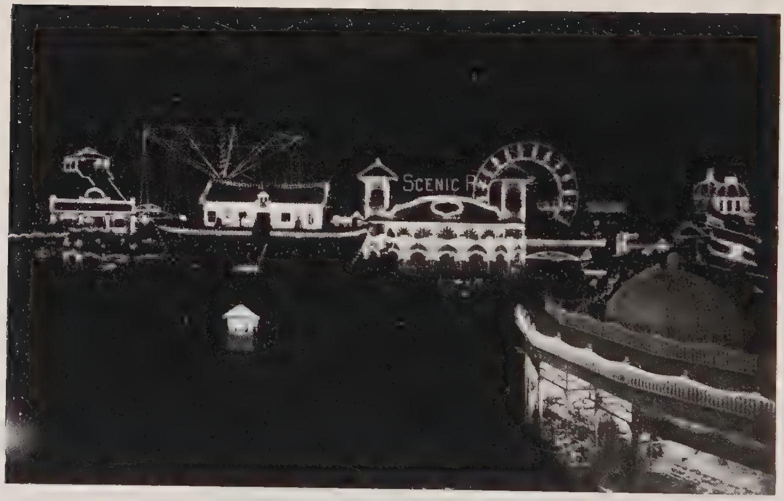

Fig. 273.—General View, Blackpool Pleasure-grounds.

In Blackpool, proprietors of business premises are not slow to take advantage of coloured light as an advertising medium; we illustrate in

Fig. 276, as an example, 'Collinson's,' the well-known café. From the large illuminated teapot situated on the front of the premises a message is immediately conveyed to passers-by. The lamps round the building are coloured, so that the whole installation makes an attractive medium, and an advertisement.

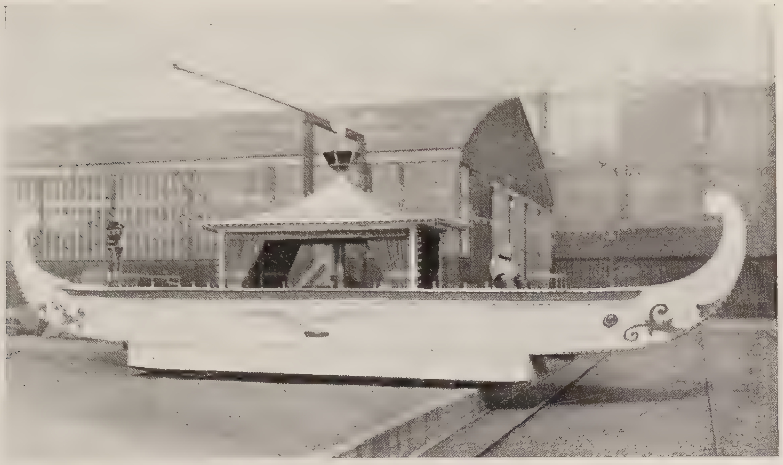

Fig. 274.—A Converted Tramcar (Day).

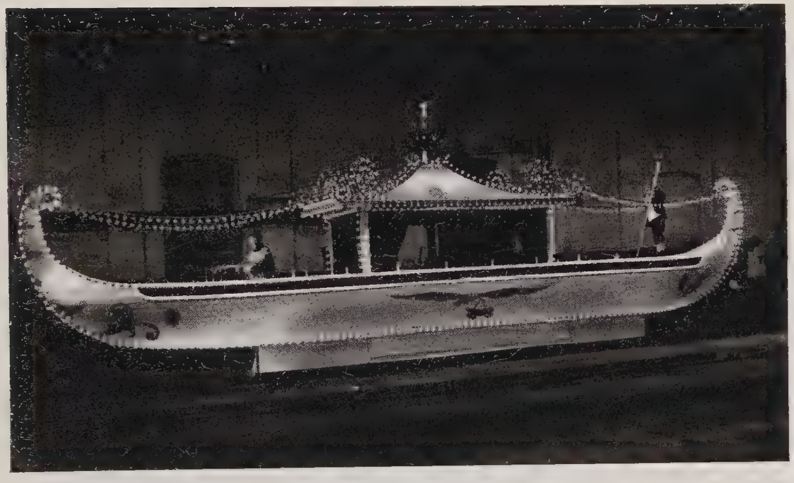

Fig. 275.—A Converted Tramcar (Night).

The illumination of pierheads at seaside resorts has considerably developed during recent years. In construction pierheads and

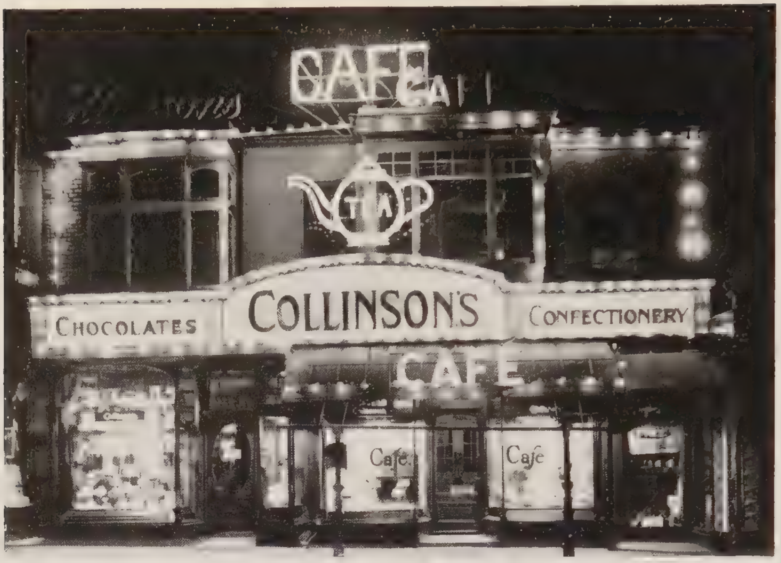

Fig. 276.—Collinson's, Blackpool, realizes the Attractive Power of Light.

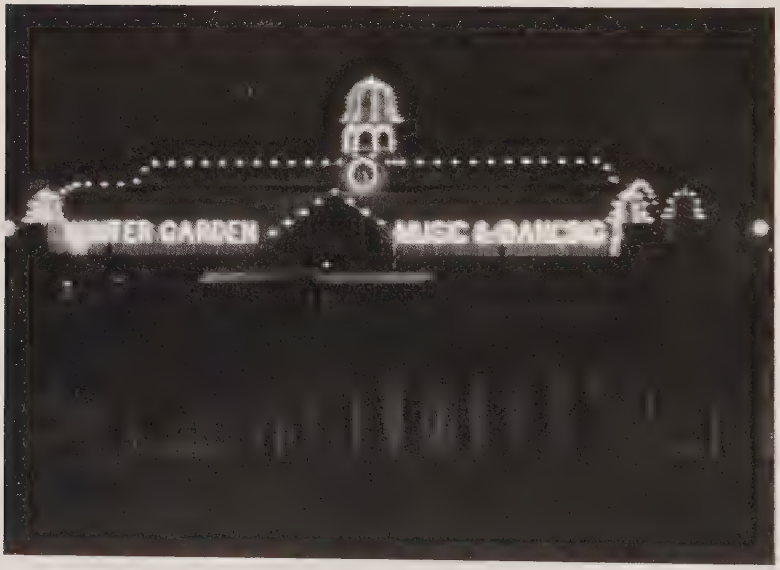

Fig. 277.—The Pier and Pavilion, Southend.

pavilions are much the same, so that, generally speaking, one method of illumination will apply to all.

An excellent example of pier and pavilion lighting is illustrated in Fig. 277; our photograph was taken at Southend. The pavilion is outlined with colour-sprayed lamps, and the standard lamps are equipped with flambeau units. The design is clear and simple, a feature which is very desirable in this class of lighting. A pier is always situated at some distance from the shore, and it can be seen along the whole length of the promenade. Spectacular designs, when viewed from an angle, merely look like a forest of lamps. Simple designs, therefore, are better appreciated.

CHAPTER X

THEATRES, CINEMAS, CLUBS, HOTELS, AND DANCE HALLS

Ceiling Units—Symmetrical Lighting—Proscenium Arch, Tivoli—Auditorium, Tivoli—The Domes, Tivoli—Capitol Theatre—Main Entrance, Capitol Theatre—Main Entrance Hall for Small Theatre—The Ideal Foyer—Aisle Lighting—Special Exit Unit—Clubs—Ceiling Units—Balcony Units—The Café Royal—Refreshment - Buffet Lighting—Antique Units—Empress Rooms, Kensington Palace Hotel—Lighting of Small Dance Halls.

Each passing year gives birth to more and more cinemas and theatres, and in the matter of lighting it must be said that vast improvements upon old systems have been made. It is to be regretted, however, that in too many theatres carbon-filament lamps are still in use, merely because the advantages of the modern gas-filled lamp are not understood.

Electric-lamp manufacturers are not to blame, and the fault does not lie with illuminating engineers in general; it can be traced, however, to managements of theatres, who do not realize the importance of good lighting with regard to their productions. This was brought home very forcibly to one of the authors a short time ago when he was discussing the subject of theatre lighting with a well-known actor-manager. It was suggested to the actor that improved lighting in his theatre would attract more patrons. The reply received was: ‘My patrons come to see me act, not to see my lighting.’

One reason why transition from carbon- to metal-filament lamps has been slow is that it is believed in theatre electrical departments that modern gas-filled lamps are incapable of withstanding the rough handling to which they are subjected when battens are moved, or when they are knocked by scenery. This, however, is no excuse for the retention of inefficient lamps whose excessive energy consumption swells the electric-light bill to such a great extent. We have ample proof that the modern gas-filled lamp is very robust and will therefore withstand rough usage; we have evidence that lamps have fallen from comparatively great heights and the bulbs have not broken and the filaments have been uninjured. We have also known street lamp standards to be knocked down and broken and yet the lamps have been unimpaired. These facts should inspire confidence in the ability of gas-filled lamps to meet every theatre requirement.

We have known cases where gas-filled lamps have been tried and have been condemned as unsuitable; this is in positions where lamps have been connected to circuits controlled by dimmers which have been designed for use with carbon-filament lamps. There is a considerable difference in the characteristics of carbon- and metal-filament lamps, and dimmers designed for the former will not reduce the candle-power of the latter to the same degree of efficiency. It is therefore essential, when gas-filled lamps replace carbon lamps in the theatre, to install dimmers which will produce the desired effect. This, of course, means additional expense, a fact which may account for the reluctance in changing over.

The theatre, almost above all places, gives opportunities for the exploitation of colour, and for systems of lighting which harmonize with architectural features; the latter are an essential of the theatre, and, since they are viewed entirely under artificial light, it may be said that the architectural features cannot be fully appreciated unless a good system of artificial lighting is installed.

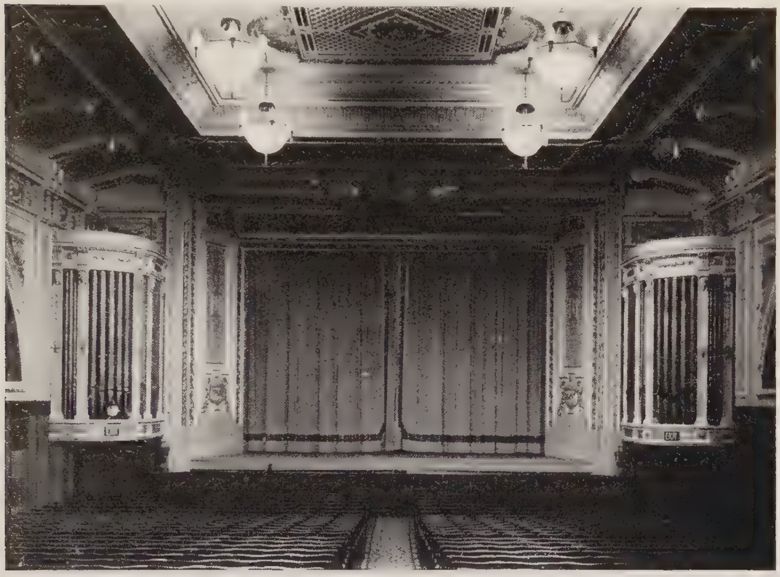

FIG. 278.—SYMMETRICALLY-SPACED CEILING UNITS.

The nature of the lighting system in a theatre will depend to a very large degree upon the class of the latter. In a theatre devoted to high-class plays and operas the architectural features often include masterpieces in sculpture. The lighting units, here, would be selected with these features in view, because it is realized that anything garish or glaring would be out of place and quite unsuitable. On the other hand, in a variety theatre, where the performance is in much lighter vein, brilliant and spectacular lighting is much more suitable ; by brilliant is meant a bright effect without glare.

With regard to the cinema theatre, the day has long passed when pictures were shown in a darkened room because the slightest outside light would detract from the clearness of the picture. Recent years have seen considerable improvements in the design of projection apparatus, and in methods of obtaining and developing photographic films ; these improvements, in conjunction with the higher intensities of light projected upon the screen, will now permit a certain amount of illumination in an interior without affecting the quality of the pictures. In this direction the advantages of coloured light are realized, and the most modern theatres have extensive installations in which colour effects are prominent features.

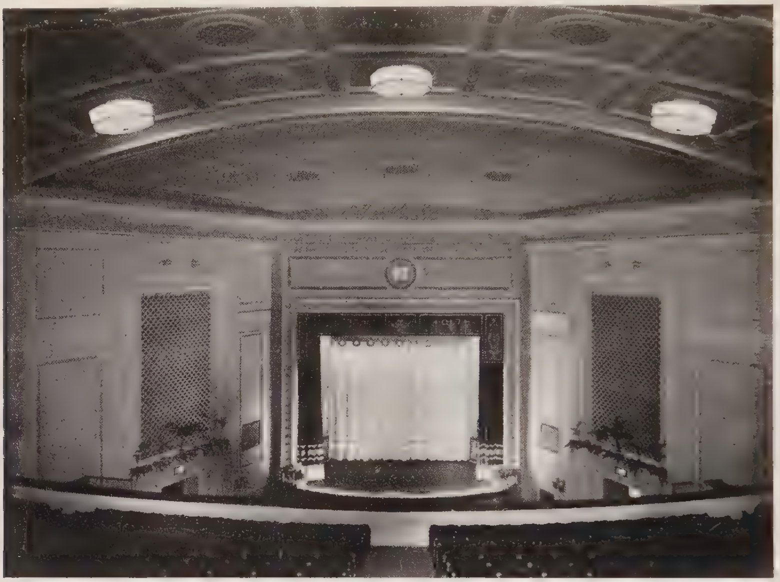

FIG. 279. —OCTAGONAL UNITS ARE SEEN TO ADVANTAGE IN SQUARES'

Theatre-lighting installations can be divided into three classes :—

1. A central ceiling fixture, or a number of ceiling fixtures with bracket fittings round the balcony and small decorative units in the boxes.
2. A number of small single units studded round the proscenium arch and ceiling.
3. Indirect or semi-indirect units, and concealed units.

The first system is in most general use, and is installed in theatres of the higher class. As a general rule central units are of a massive character, but they are nevertheless artistic. When a number of smaller units are fitted, excellent results can be obtained provided that the units have been selected with regard to the colour of the interior and the decorative features of panelling, etc.

A theatre in which are fitted four ceiling units is illustrated in Fig. 278; a glance at this illustration will serve to show that the general effect is bright and pleasant. Although these units appear to be of massive design, they are of the 'home-made' variety and are very light. Each unit is constructed of a thin metal octagonal band, and fitted to the bottom is an inverted silk shade. Round the band are fitted four flambeau units with satin-finished shades. The inverted silk shades contain a number of white-sprayed lamps, and the flambeau shades contain flame-coloured lamps; this provides just the touch of colour which makes a pleasing contrast.

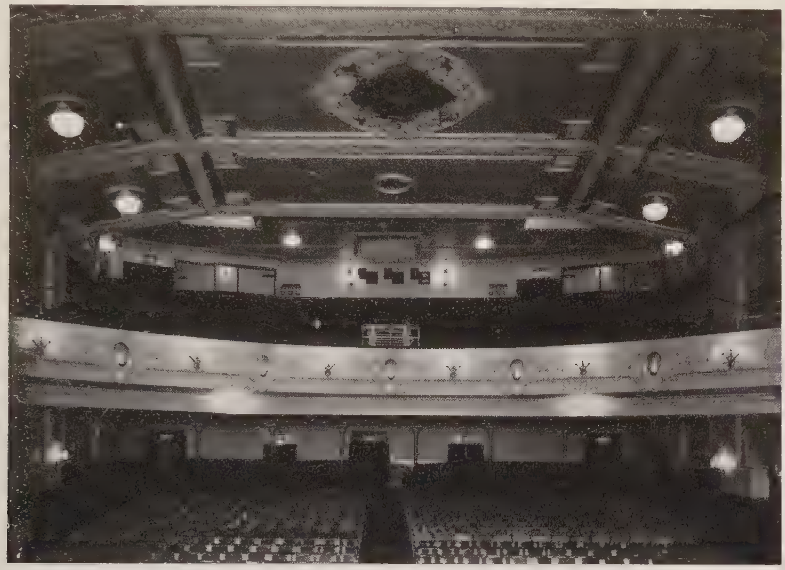

FIG. 280.—SYMMETRICAL LIGHTING ENHANCES THE APPEARANCE OF AN INTERIOR.

Another interior, but with a different method of illumination, is illustrated in Fig. 279. From this illustration it will be understood what is meant by a lighting system harmonizing with architectural features. Octagonal lighting units, fitted in alternate squares, enhance the appearance of the ceiling design.

In Fig. 280 is illustrated an interior in which both ceiling units and balcony lights are shown; the photograph was taken from the stage. It will be seen that this interior is quite suitable for a central lighting unit, but this would have to be very large to transmit light to the extreme sides of the theatre. Such a large unit would obliterate the decorative features of the centre panel; it was to show the latter to advantage that a number of smaller units were installed. Regarding the balcony units, these are 3-light units of unique design. They are crossed flambeau units held together by art metal-work; the shades each accommodate a yellow-sprayed lamp. This photograph was taken by means of the lighting units alone, and it serves to show how the beauty of architecture can be emphasized by the application of correct lighting. Note how clearly the ceiling and balcony ornamentation can be seen.

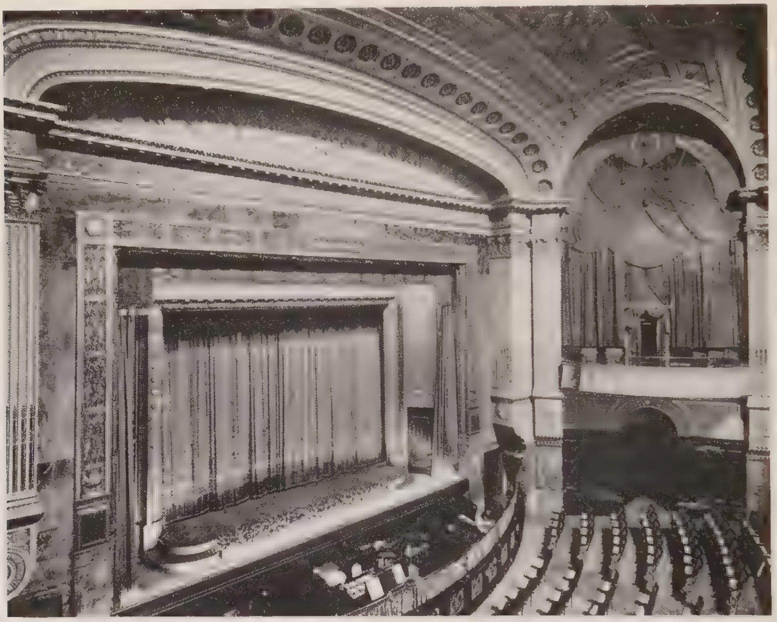

Fig. 281.—The Proscenium Arch, Tivoli, Strand, London.

A typical example of concealed lighting is illustrated in Fig. 281; our photograph is of the proscenium arch in the Tivoli Theatre, Strand, London. Seated comfortably in a stall or balcony seat, and looking towards the proscenium arch, one is impressed with the clear, clean beauty of the mouldings. Every detail is picked out in light, yet from no discernible source, unless, from a seat in front of the stalls or from one of the boxes, one glances back at the auditorium. Then the source of illumination is explained, because a number of units can be seen sunk flush with the balcony front; these project floods of light at various angles over the whole proscenium.

A general view of the auditorium in this theatre is illustrated in

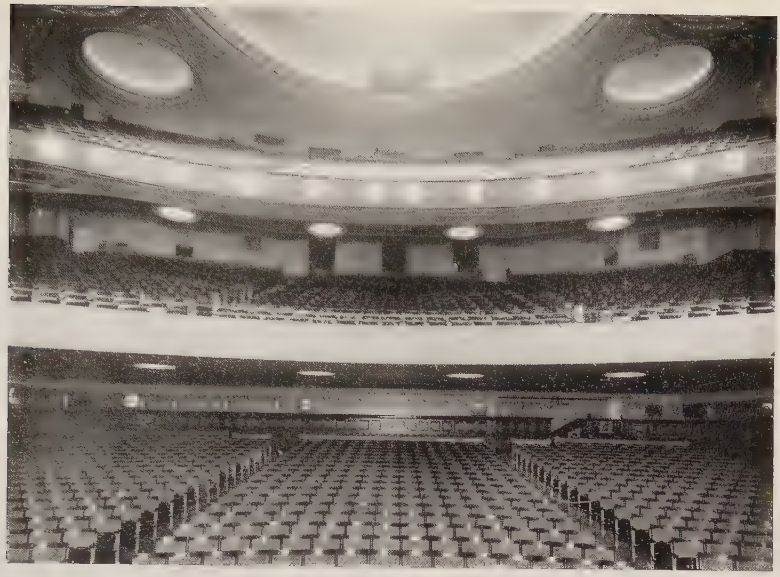

FIG. 282.—THE AUDITORIUM, TIVOLI, STRAND, LONDON.

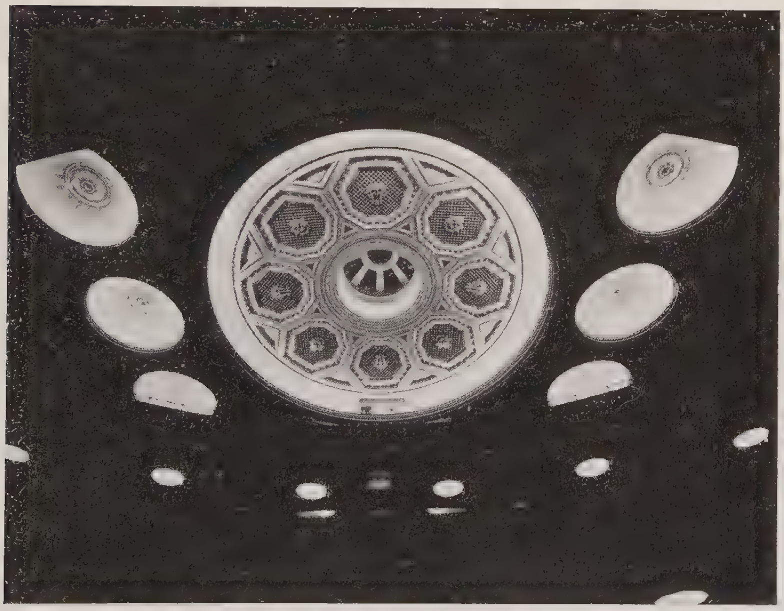

FIG. 283.—THE DOMES, TIVOLI, STRAND, LONDON.

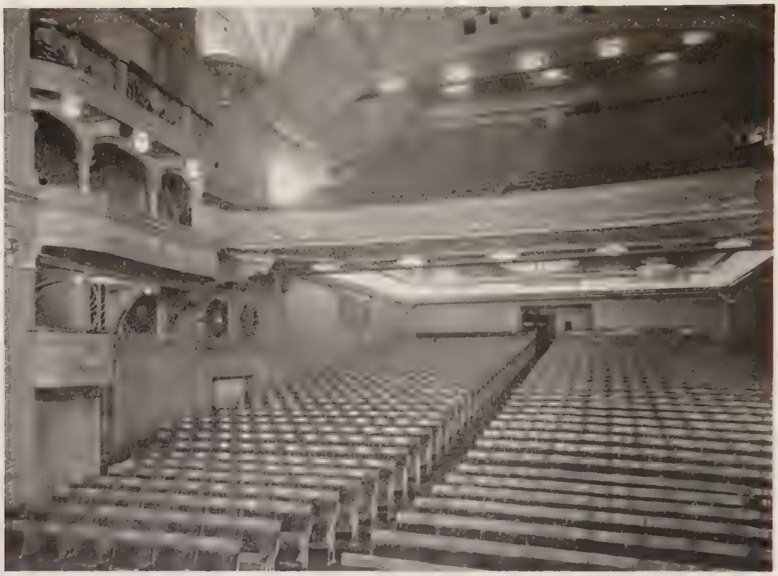

FIG. 284.—AUDITORIUM, CAPITOL THEATRE, LONDON.

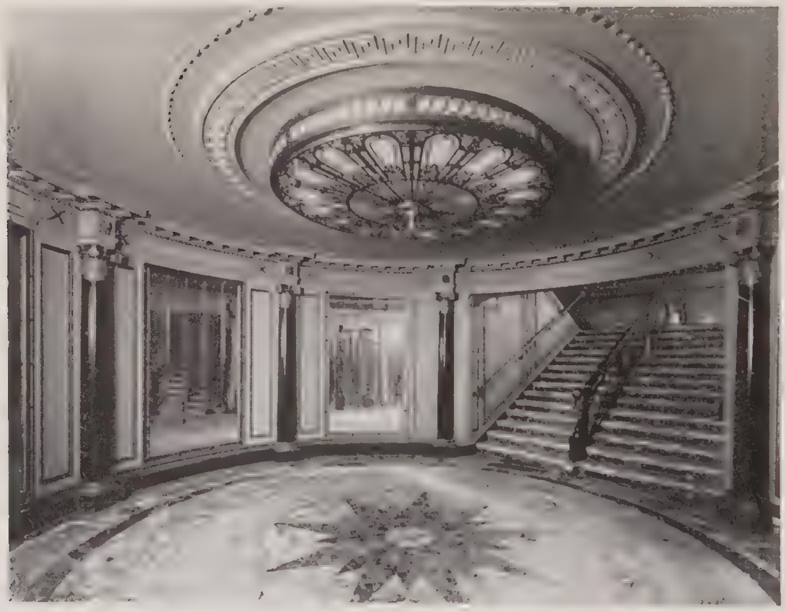

FIG. 285.—MAIN ENTRANCE HALL, CAPITOL THEATRE.

Fig. 282; here the spacing of the balcony units should be noted. This photograph was taken from a point exactly in the centre of the stage, so that the whole of the general lighting units, and their relative positions, can be seen.

The outstanding feature in the illumination of the Tivoli Theatre is the 'domes'; these are illustrated in Fig. 283. Here, again, the photograph was taken from such an angle as to show their relative positions. The enormous central dome is 54 feet in diameter, and the six subsidiary domes are 16 feet in diameter. When illuminated they create a profound impression of colour and beauty. They appear as masses of perfectly even colour which suffuse the whole of the interiors with any desired tint; the tints are controlled by means of specially designed dimmers. A charming effect is obtained when the lantern in the centre is equipped with amber lamps, the dome itself with cornflower-blue, and the subsidiary domes with rose-pink.

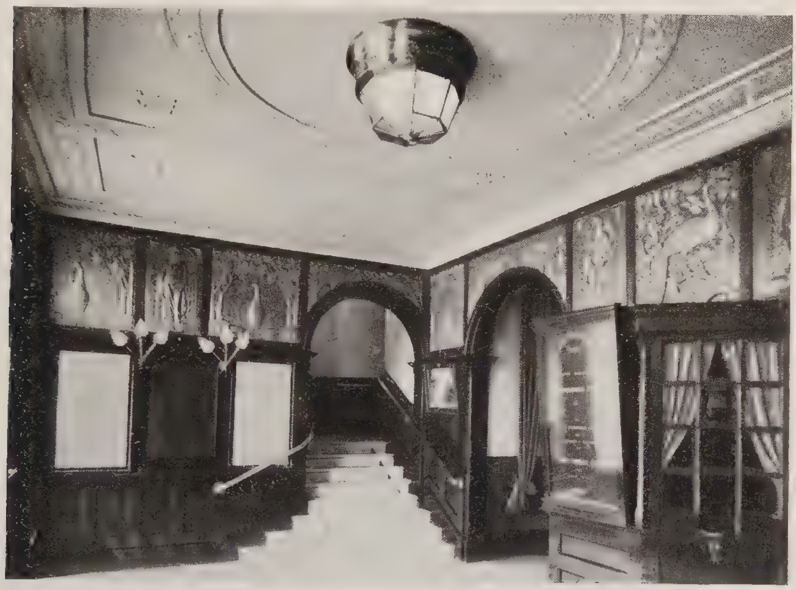

Fig. 286.—Entrance Hall for a Small Cinema.

As a striking contrast to the Tivoli Theatre we illustrate the auditorium of the Capitol Theatre, Haymarket, London (Fig. 284). The whole of the units shown in this illustration are equipped with colour-sprayed lamps; even the small units shown in the boxes on the left of the illustration are equipped with lamps in four colours. They are connected to dimmers and arranged on circuits which permit single and combined colour control. The larger units are similar in design

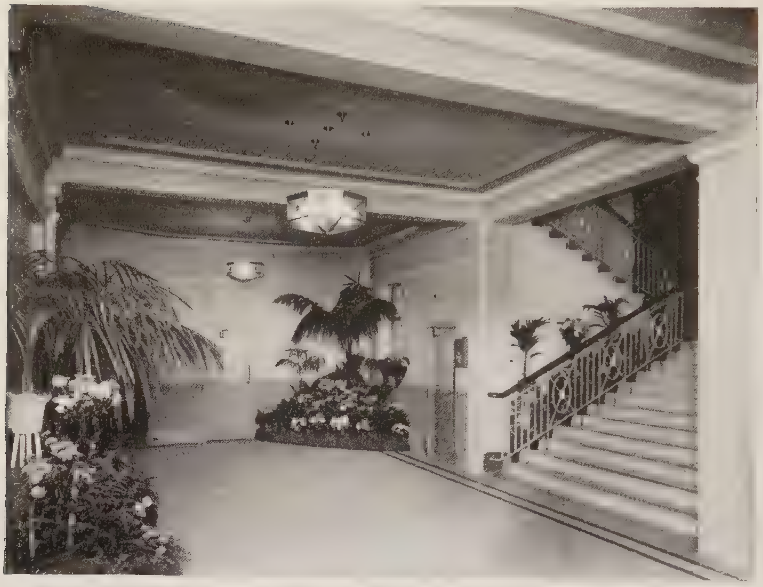

Fig. 287.—The ideal Theatre Foyer.

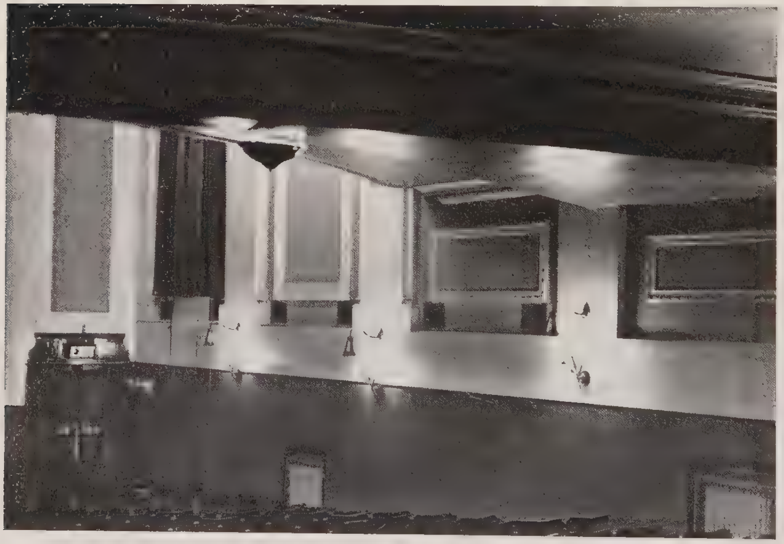

Fig. 288.—This Installation meets exacting requirements.

and construction to the unit installed in the main entrance hall, which is illustrated in Fig. 285. It will be seen that this is a magnificent ceiling fixture, very ornate, and with decorative glass panels. The whole of the lamps in this unit, however, are of one colour only—amber.

The main entrance hall of a small theatre is illustrated in Fig. 286. This contains a central unit which accommodates white-sprayed lamps. The glass panels are amber, so that the whole unit appears to be flooded with amber-coloured light. The effect is charming, and provides a pleasant contrast to the flame-coloured lamps which are accommodated in the shades of the flambeau units seen on the left of this illustration.

The ideal theatre foyer is illustrated in Fig. 287. Its beauty is enhanced by the angular design of the lighting units and the unique method of fitting them to the ceiling; a foyer of such a pleasant appearance is sure to put patrons on good terms with the management immediately it is entered.

Side-aisle units play a very important part in the providing of comfort for patrons; it is by their means that seats are located when a play or picture has commenced. In Fig. 288 is illustrated the interior of a theatre, showing a number of these units installed; one of these is illustrated in detail in Fig. 289. The three flambeau units are for general illumination, and in this respect they are both efficient and decorative. Above the flambeau unit will be seen a conical bracket unit; this is a special unit for aisle lighting.

Light without glare, and from practically a concealed source, characterizes this unit. The shade is long and conical, and the apparent height of the lamp filament inside the shade can be judged. The spacing points are equidistant, but the height of the units, and consequently the angle of cut-off, is such that the whole of the aisle is evenly illuminated. Owing to the reflector being deep, the lamps cannot be seen unless, when immediately under a unit, one looks deliberately up into the reflector.

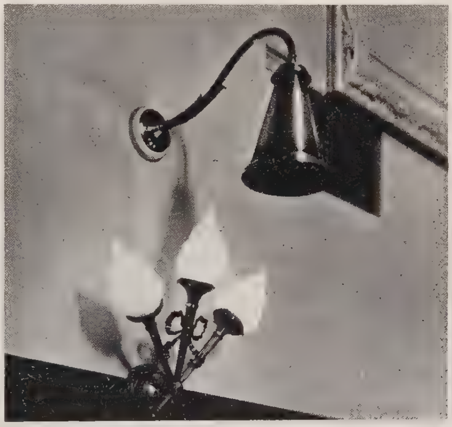

Fig. 289.

An exceptional EXIT unit is illustrated in Fig. 290; this is quite a recent development. The unit is of the ordinary box type, equipped with white-sprayed lamps. The EXIT side of the unit is fitted with the usual sheet of white opal glass, but the bottom and sides of the box are glazed with amber glass. This effectively illuminates the back aisle, and when the units are fitted over a door the bolts can be clearly seen. Since the majority of these units are at the back of the theatre, the light from them does not distract the attention of patrons from a play or picture.

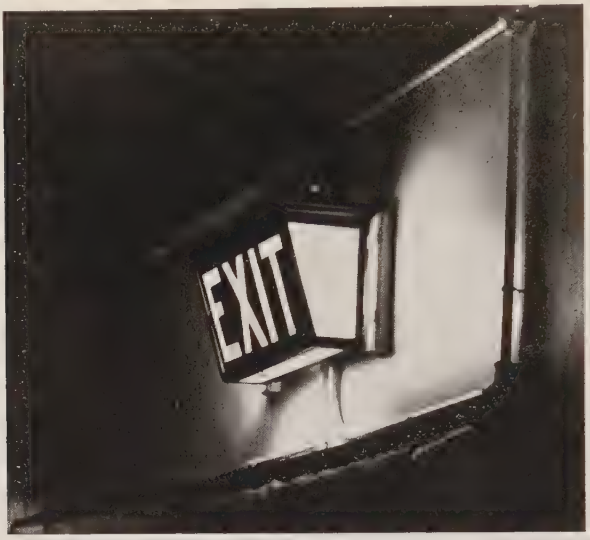

FIG. 290.—A VERY EFFICIENT EXIT UNIT.

Comfort should always characterize every feature that a club has to offer to its members. Restful and decorative illumination is one of the most essential comforts, comforts which go far to make the club popular. Progress in the design of decorative lighting units has been so rapid that many notable examples of a combination of the art of the architect and the illuminating engineer are now to be seen. One of the best examples is a well-known club near Piccadilly, London, the interior of which is illustrated in Fig. 291. This club is situated *under* the Capitol Theatre, Haymarket, London, and it is therefore necessary to use artificial lighting throughout the whole of the day.

The most charming feature of the club is probably its decorative ceiling. The centre, which is circular in shape, somewhat resembles a large daisy; the flower is actually an enormous lighting unit. In the centre, a number of frames and glass panels are woven into an artistic pattern; from this pattern the ‘petals’ extend to the extreme edge of the ceiling; each petal is formed of an opal-glass sheet, and there are twenty-four sheets in the complete design.

In the ceiling behind these glass panels are fitted a large number of

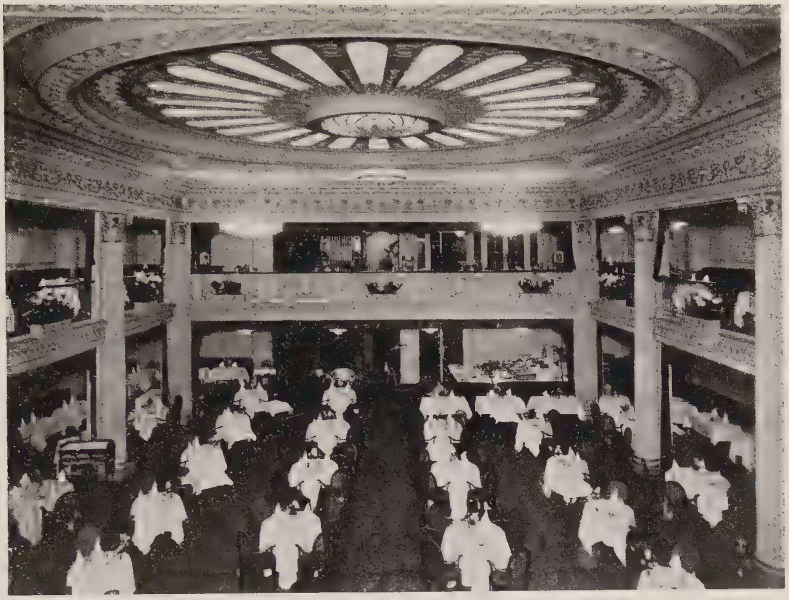

Fig. 291.—Note the Artistic Ceiling Unit.

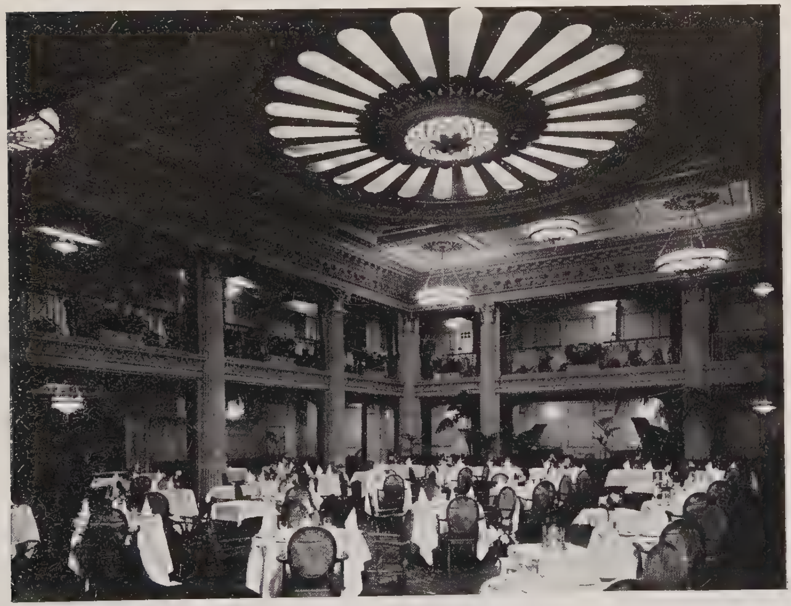

Fig 292.—The Unit illuminated.

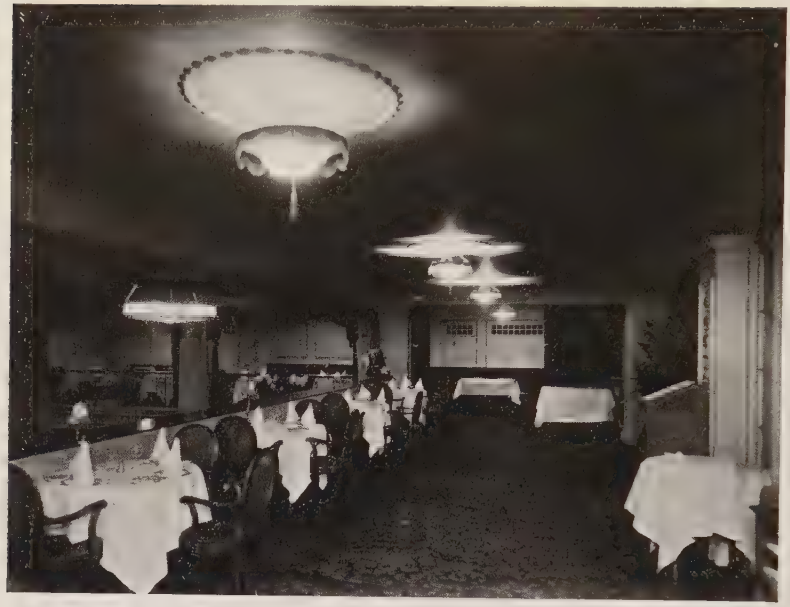

FIG. 293.—A BALCONY.

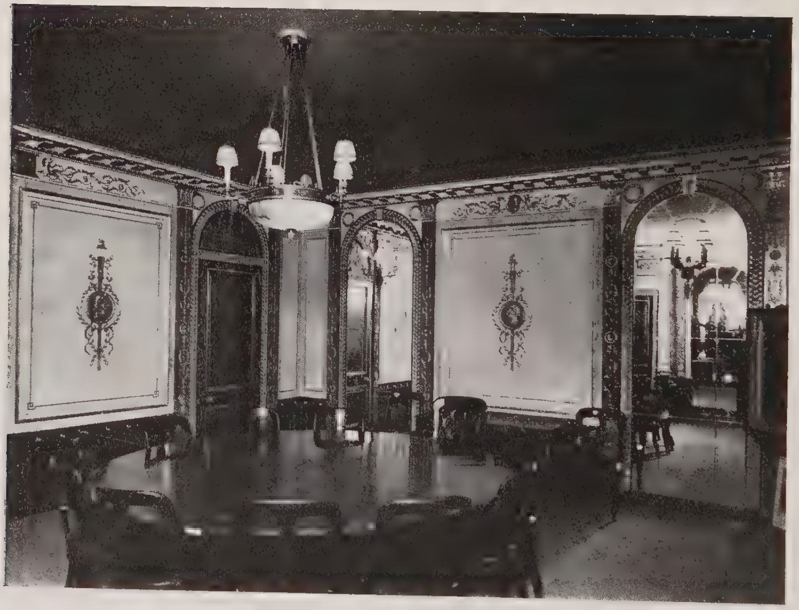

FIG. 294.—BOARD ROOM, CAFÉ ROYAL, REGENT STREET.

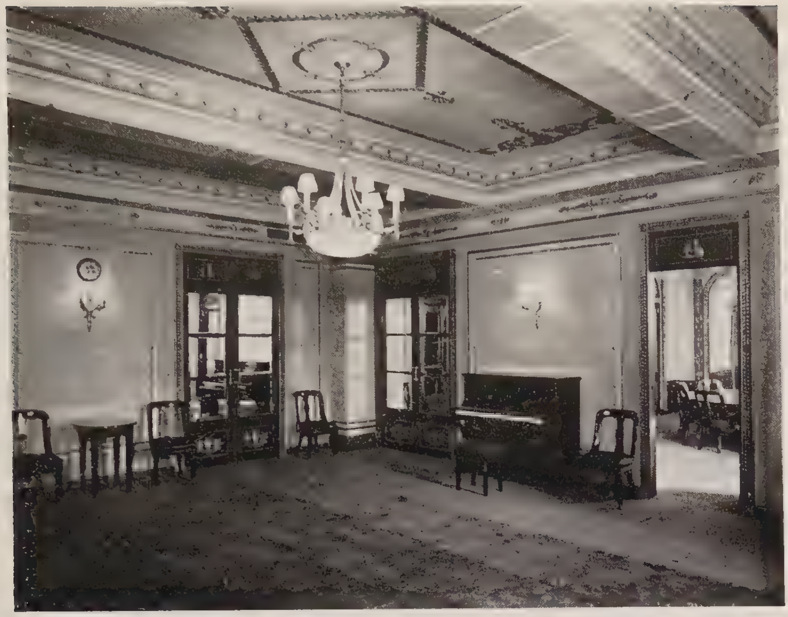

FIG. 295.—ONE ROOM, CAFÉ ROYAL, REGENT STREET.

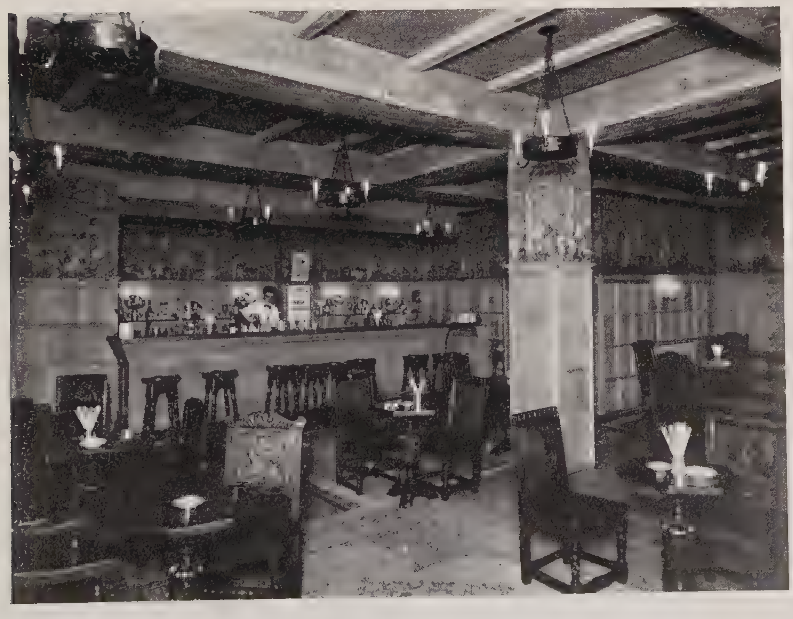

FIG. 296.—ANTIQUE LIGHTING UNITS ARE IN HARMONY WITH THE ARCHITECTURAL FEATURES.

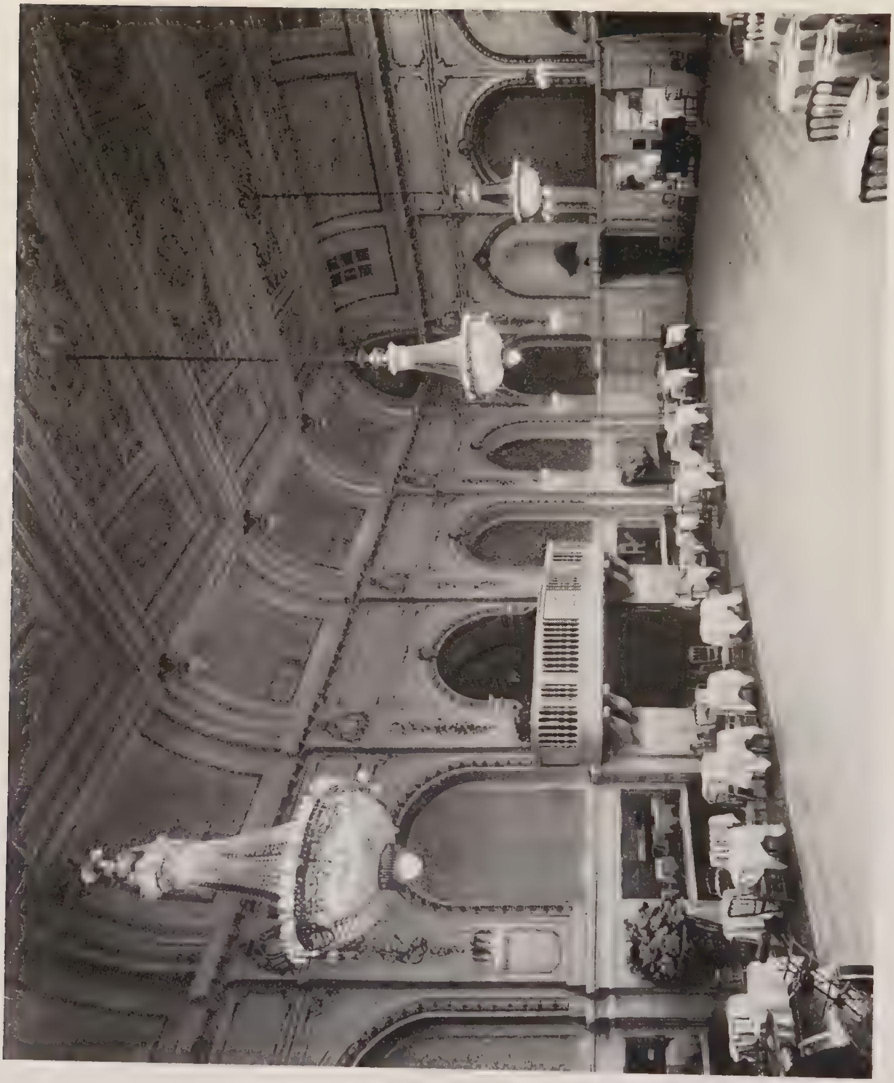

Fig. 297.—Note how the Ceiling Decorative Features stand out when Light is correctly applied.

colour-sprayed lamps of various colours. These are connected to circuits in such a manner that they can be controlled singly, or combined, through dimmers. At the moment our photograph was taken, amber was the predominant colour in the unit.

Further decorative lighting units are illustrated in Fig. 292; this photograph was taken from the floor of the club to show the effect of the central unit and the combined effect with other units. Regarding the latter, it will be seen that in design they are octagonal in shape and in the form of baskets; the method of suspension of these units is an appropriate decorative feature. Each unit is equipped with colour-sprayed lamps of various colours.

In Fig. 293 is illustrated one of the balconies in the club. The lighting units are manufactured from various-coloured silks, and are equipped with colour-sprayed lamps. Special arrangements enable each colour to be separately used. The light from these units is perfectly distributed; the shadows are very soft, and glare is entirely absent. In the left of our illustration can be seen one of the ceiling units previously described. The total absence of glare is apparent, not only from our illustration, but from the fact that diners on the balcony have the unit in close proximity to their eyes. The illumination from it is pleasant, and does not interfere with vision in the slightest degree.

In the hands of the up-to-date hotel manager electric lighting provides a means of obtaining added comfort for his patrons. In the selection of lighting units, therefore, artistry and utility should be the keynotes. In Figs. 294 and 295 are illustrated two rooms in the Café Royal, Regent Street, London. In the design of the lighting units in these rooms beauty and usefulness were the chief considerations.

In each case the units are of period design, and are quite in keeping with the decorative features of both panelling and doorways. In Fig. 295 the panels are not quite so decorative as in the previous illustration, but the artistic touch is supplied by the 2-light bracket units fitted in the centre of the panels.

The refreshment-bar of a hotel or club calls for special treatment in the design of the lighting installation; so much depends upon the location of the units and their suitability for harmonizing with the general surroundings. In Fig. 296 is illustrated a refreshment-bar constructed on old-fashioned principles; the massive oak beams are an essential of this type of architecture. In an interior of this nature no type of lighting unit would be suitable unless it was of antique design.

In the installation illustrated the requirements are fully met by the use of old-time candle fittings; brass bands suspended by chains, crude arms and pieces of tube, split at the ends to receive candle lamps, form antique units that are not only artistic but create a cosy ‘atmosphere.’

Almost every hotel has attached to it a dance-hall; here the lighting arrangements call for special attention. One of the most beautiful ballrooms in the world is in the Empress Rooms of the Kensington Palace Hotel, London. Its beauty is due, in no small measure, to the magnificent lighting installation. In the illumination of this room, illustrated in Fig. 297, are enlisted the services of three massive crystal chandeliers. Inside each chandelier are fitted no fewer than eighty yellow colour-sprayed lamps; the effect is to provide an abundance of yellow illumination reminiscent of bright sunshine. This lighting is supplemented by a number of 4-light bracket fittings symmetrically situated round the walls; these, also, are equipped with yellow colour-sprayed lamps. In addition, a large number of tubular lamps are fitted along the base of the arches to be seen round the room; these are entirely out of the sight of diners and dancers. The effect is to flood the walls with amber-coloured light.

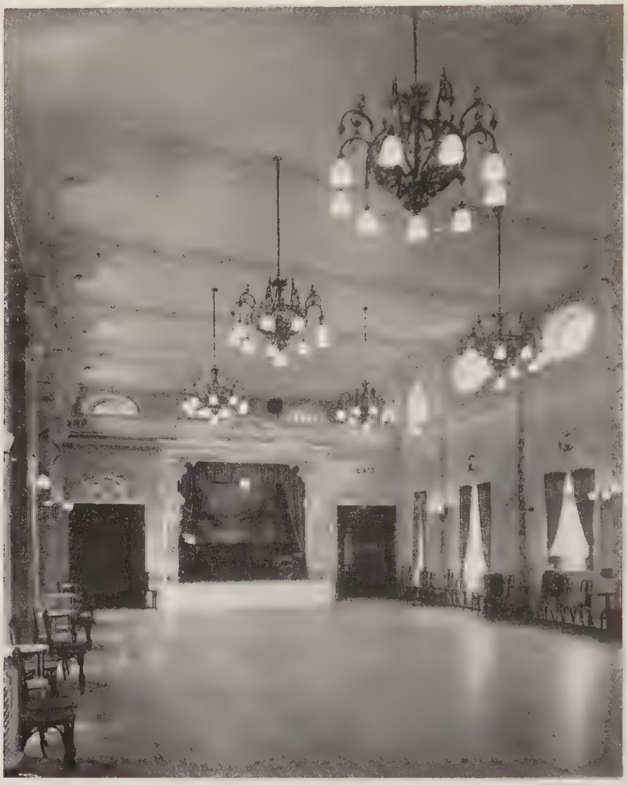

FIG. 298.—AN ATTRACTIVE DANCE-HALL.

Smaller ballrooms can be made exceptionally attractive by the installation of decorative lighting units. Such an installation is illustrated in Fig. 298, which shows the interior of the ballroom of the Star and Garter Hotel, Putney Bridge, London. In this installation a number of artistic electroliers are suspended from the ceiling; each unit is equipped with nine salmon-coloured shades, each of which accommodates a clear gas-filled lamp; these units are supplemented by a number of 2-light bracket fittings located round the walls. When the whole of the units are in use the room is flooded with an abundance of warm, mellow light.

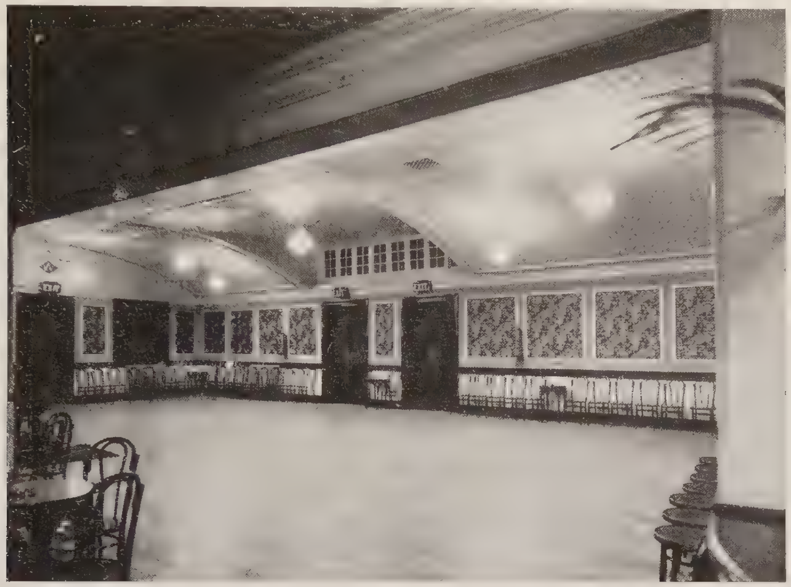

FIG. 299.—NOTE THE ILLUMINATION ON THE FLOOR: IT MAKES FOR DANCING IN COMFORT.

A contrast in ballroom lighting is illustrated in Fig. 299; this is the interior of a dance-hall with a very low ceiling. A number of diffusing units are fitted in this room; the requirement to be met in this installation was an abundance of well-diffused light. Our illustration indicates the success of the installation.

CHAPTER XI

THE MANUFACTURE OF VACUUM AND GAS-FILLED LAMPS

In General—Some Early Types of Electric Lamps—Treatment of Tungsten Ore—Swaging—Wire-Drawing—Weighing Filaments—Flanging—Assembling Bulbs and Filaments—Mounting the Filament—Clamping Filament Ends—Exhausting—Photometry—Capping—Final Testing—The Argon Gas Plant.

One of the essentials of the modern electric lamp is tungsten; this is manufactured from a kind of ore mined in Australia. The ore is crushed and ground to a powder, which is washed with acid to remove impurities and to convert the calcium tungstate contained in the ore into tungstic oxide. Treatment of this oxide with ammonia produces a colourless solution of ammonium tungstate, from which a bright yellow powder is precipitated by a further addition of hydrochloric acid. This powder, which contains pure tungstic oxide, after ‘cooking’ in a series of pans, becomes a dry material not unlike yellowish plaster of Paris.

A quantity of this powder is placed in a long quartz tube which is traversed by a stream of hydrogen and heated by gas flames; this treatment reduces the oxide of tungsten to metallic tungsten. From the furnace there is taken a fine grey-black powder notable for its great weight—this is pure tungsten. Simple as this process of metal-making appears, it has its scientific secrets; one of these is that, although the filament of a modern electric lamp is described as a tungsten filament, it is not wholly so, since it has been found that the admixture of the tiniest proportion of certain substances makes the tungsten filament much more durable.

In the change from tungsten powder to tungsten wire the aid of pressure, heat, electricity, and a mighty hammering is enlisted. As a first step, a quantity of tungsten powder is packed into a narrow channel between thick steel walls; a slab of steel closes this channel and makes a box of it. The whole arrangement is then placed in a hydraulic press and subjected to such enormous pressure that the slab squeezes the powder into a stick about the size of a piece of ordinary sealing-wax, which, although brittle, can be handled with a certain amount of freedom. The powder, in fact, has been squeezed solid, but it is not solid enough to be ‘worked.’

A heavy current of electricity is now passed through the stick of tungsten, which is hung vertically in a protecting envelope of hydrogen and nitrogen gas during the process. The heat generated by the current welds the particles of tungsten together and the brittle stick becomes a metal rod, fit for mechanical treatment.

The treatment it receives is drastic ; it is heated and hammered until it is drawn out long and thin by a process known as swaging. The deafening noise made by the swaging machine is a token of the vigour of the process, which has the effect not only of lengthening the rod into a thick wire, but of making the metal more ductile ; that is, it is more capable of being drawn into finer and finer wires.

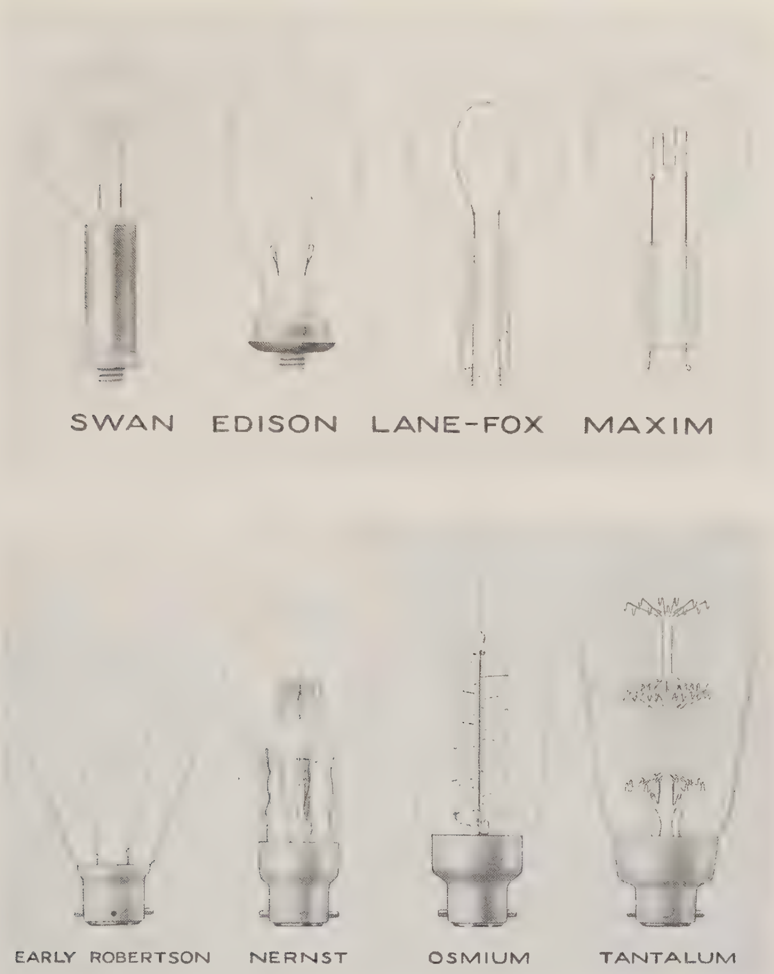

Fig. 300.—Some Early Types of Electric Lamps.

Wire-drawing is an ancient industry, but one that never loses its fascination. To watch a short rod being transformed, stage by stage, into an enormous length of the thinnest wire is to gain anew a sense of the inveterate ingenuity of man ; yet the process is straightforward. It consists of forcibly drawing the rod, which is first heated, through a hole a little smaller than the rod, the metal lengthening as it is drawn. Again it is heated and drawn through a smaller hole, and so on until the desired fineness of wire is obtained.

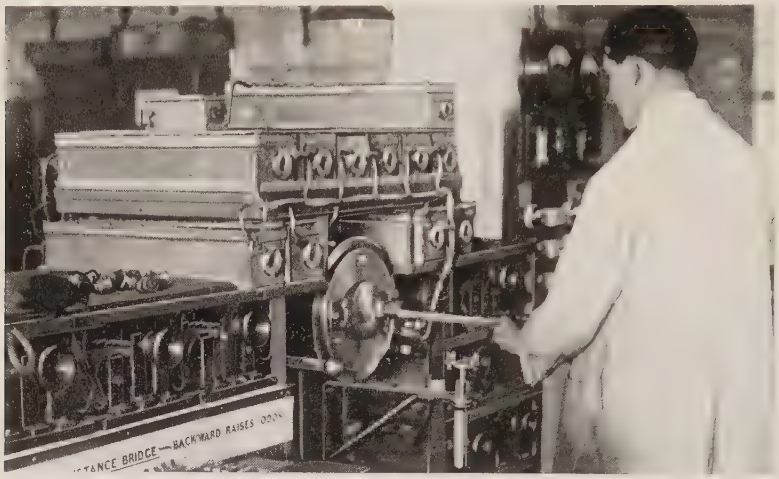

Fig. 301.—Swaging Hot Tungsten Bars.

Fig. 302.—A Process in the Treatment of Tungsten Ore.

One thing that puzzles people who see tungsten wire-drawing for the first time is how the end of the wire is got into a die smaller than itself, so that the rest of the wire may be drawn through. The secret lies in a tiny crucible where a chemical—sodium nitrate—is kept 'on the boil.' The end of the wire is dipped into this chemical and is almost immediately eaten away to a sharp point.

The metal actually gains in toughness with each drawing; it is the die through which it is drawn that suffers. Diamond dies are used, and examination proves that after they have been at work the holes increase in size and sometimes get out of shape. As it is most important that the wires in electric lamps should be exactly of a certain size, a careful watch has to be kept on the dies.

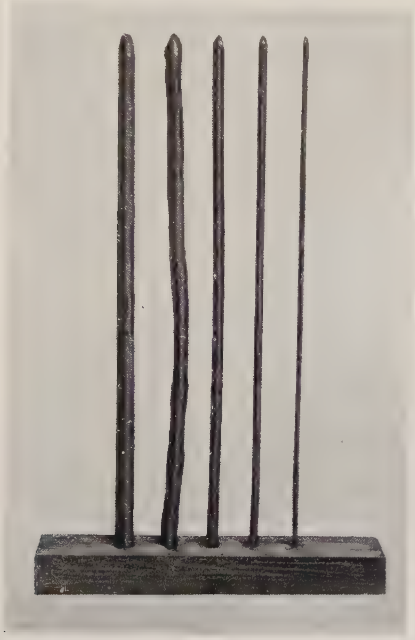

Fig. 303.—Tungsten Bars after Swaging.

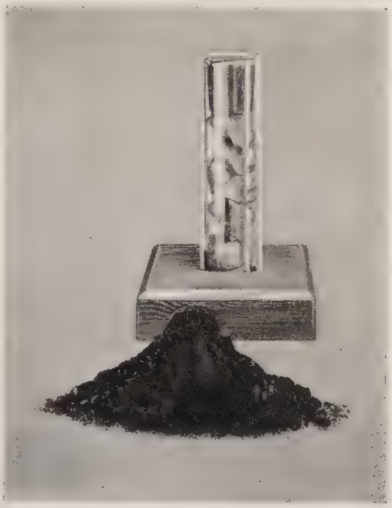

Fig. 304.—Pure Tungsten.

To maintain the dies in good condition it is necessary for a number of machines to be constantly employed. Each die, when worn, is reground to the size next above its original size, so that there is no waste of costly gems. The grinding in itself is a most interesting process. It is done by means of ordinary sewing needles, which are moved round and round inside the hole; what could be more curious than that a steel needle, with a little diamond dust and oil, should be able to grind diamond, which is the hardest substance in the world?

The process is, as one might expect, extremely slow, the regrinding of a diamond die occupying as long as three weeks in some cases.

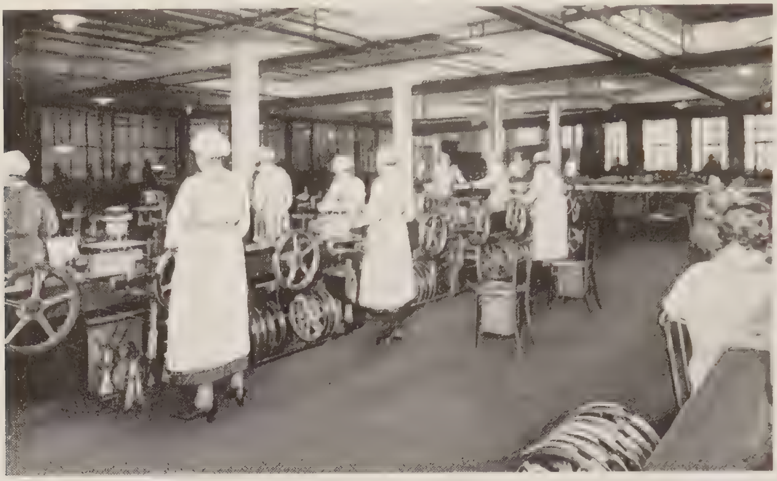

Fig. 305.—General View, Wire-drawing Department.

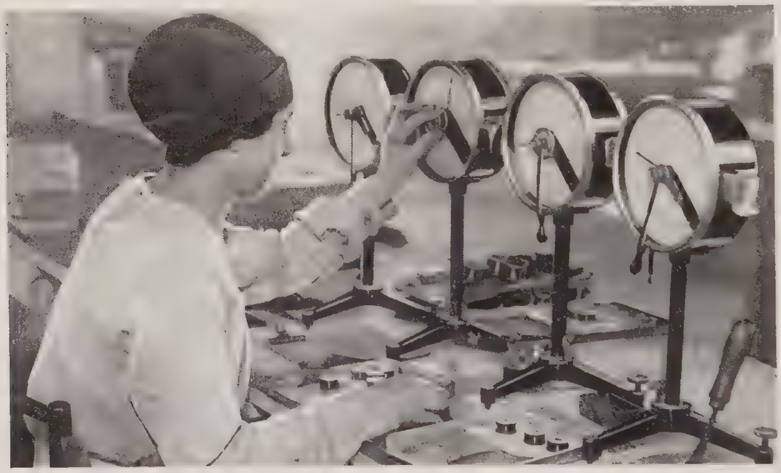

Fig. 306.—Gauging the Diameter of Fine Tungsten Wire by weighing a Known Length.

The final stages in the process of wire-drawing leave the wire conveniently wound on bobbins. The lamp-maker needs to know the exact thickness of the wire he is using, from the fact that a lamp to be used on a 200-volt circuit must have a filament different from that of a similar lamp intended for a 100-volt circuit. Although some filaments are so fine as to be scarcely visible to the naked eye, it is possible to measure them accurately. The method adopted is to weigh a certain length of wire; 200 millimetres of the wire is snipped off and the piece is 'weighed' in a very delicate balance; knowing the weight and the length, the thickness can be calculated.

This work is carried out by girls, and, as a matter of fact, there are no calculations necessary. The balances are so calibrated that the thickness of wire is directly read off a scale, the whole business taking but a few seconds. The same indirect method is used to determine the diameter of the dies: a short length of wire is pulled through each and weighed, the size of the wire being, of course, the size of the die.

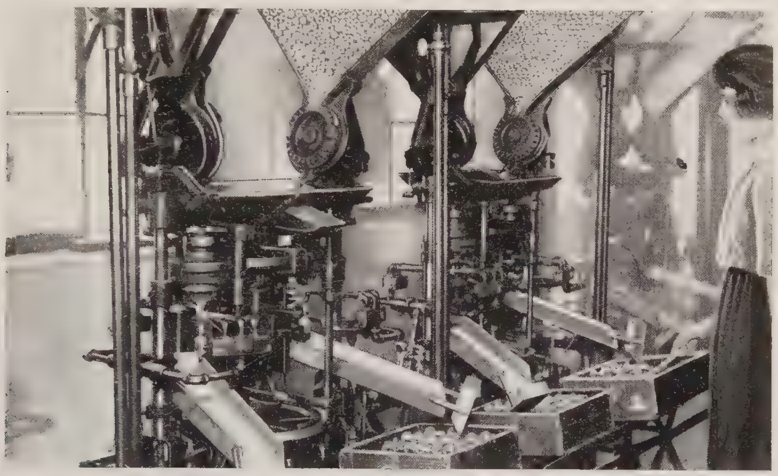

Fig. 307.—A Group of Flanging Machines.

The bobbins of wire are, like reels of cotton, classified according to thickness and arranged ready to go to their appropriate sections.

Regarding lamp manufacture, a glance at the ordinary electric lamp will show that the filament is carried on wire supports springing from a glass rod. This rod, in turn, is carried on a glass tube which has been flattened where it joins the rod. Looking closer, one sees that two wires go straight through this flattened part and join up to the filament, and that, from a small hole in the tube, immediately below the pinched portion, an inner and smaller tube runs down into the interior of the lamp cap; the object of this tube will be explained later.

These wires are termed 'leading-in' wires, and, although they seem a mere trifle, they are very important. How important they are will be seen when it is described how the foot is assembled. The outer tube of the foot is cut from a length of tubing, and one end is opened out into a kind of bell-mouth in a gas flame. This is done in a machine which automatically cuts and feeds itself with pieces of glass tube, softens the end of each in a flame, and then brings up a small instrument something in appearance like a spinning spear-head, which opens out the softened glass. The inner tube and rod are simply cut to length, and need no other preparation.

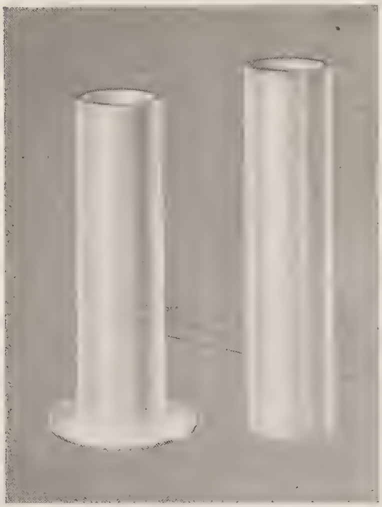

Fig. 308.—The Outer Tube of the Foot.

In another machine the tube, the rod, and the leading-in wires are welded together—again in gas flames. All these component parts are fed separately into the machine, which holds them in their proper relative position. As in many other machines, the parts under treatment move in a circle stage by stage ; at each stage a new operation is performed. Here, in the first stage, flames play upon the lower ends of the tubes and gradually soften them. A pair of pincers then comes forward, squeezes the outer tube flat over the leading-in wires, and welds the flattened part to the glass rod and inner tube.

A gas flame is then directed on to the surface of the outer or flanged tube, just opposite the point at which the inner tube is melted into the ‘pinch,’ once more raising the temperature of the glass at this spot above its melting-point. At the same time a jet of air is directed into the bore of the small exhaust tube, causing a bubble of glass to form at the heated spot and almost simultaneously to burst, thus providing the desired communication between the exhaust tube and the outer surface of the flange tube. When the whole assembled pinch is afterwards sealed into the bulb, by welding the flange of the former to the neck of the latter, the tube is therefore the only means of communication between the interior of the lamp and the outside atmosphere.

The machine just described is very ingenious, but it is not more so than the machine used in fixing the supports into the glass rod. These supports are short lengths of fine wire, bent into a hook or a pig-tail twist at the end. The wire is made of molybdenum, which is very springy and withstands the high temperature of the filament.

As in most of the processes of lamp-making, these supports were originally put in by hand. The glass rod was melted at the end and also near the top, where it was squeezed to form thicker portions known as ‘roses’ or buttons. The operator then picked previously-made supports in a pair of forceps and pressed them one by one into a part of the button softened in a blowpipe flame. Although girls engaged upon this work developed a remarkable degree of skill, fixing in support after support with a quickness and speed which almost made a machine seem unnecessary, nevertheless the use of machinery was called for in order to keep pace with other processes. Two machines are in general use: one inserts the supports singly, the foot being turned a little after each insertion to bring the next into correct position; and the other inserts an entire set of supports—which may be as many as seventeen—in one operation.

The second machine is so complicated and so quick that its movements are very difficult to follow. After the operator inserts the foot, the machine firms the roses in a gas flame, cuts off the correct lengths of molybdenum wire, forms a little hook or a pig-tail loop at the end of each length, and, bringing the other ends forward simultaneously, pushes them into the softened roses. All this is done in as little time as it would take to insert two or three single supports by hand.

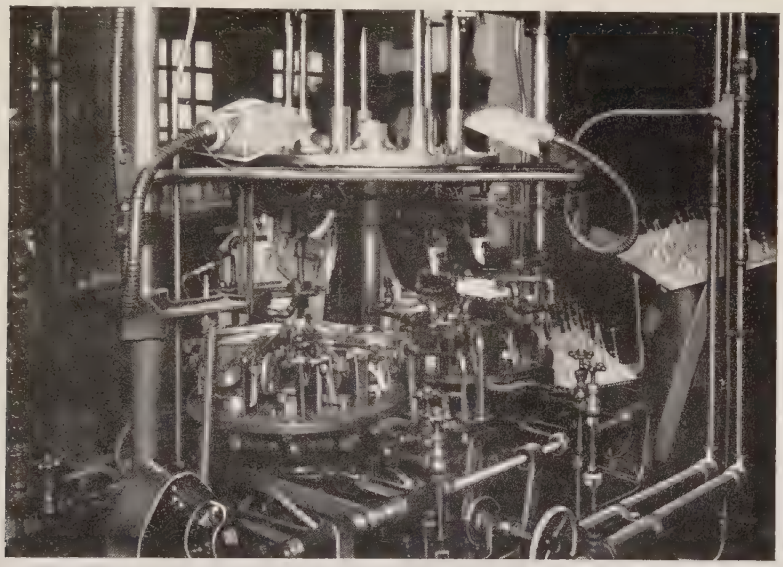

FIG. 309.—MACHINE FOR INSERTING THE FILAMENT SUPPORTS.

The 'one-support-at-a-time' machine works on much the same principle, and is used in certain cases because it is more flexible—that is, the number of supports to be inserted can be altered more readily. The 'all-supports-at-once' machine is used in departments where large numbers of lamps of exactly the same pattern are made.

At each stage in the process of manufacture the work is carefully inspected for possible errors. For instance, every machine-made foot is tested to make sure that the ends of the wire are not too close to each other in the glass where they have been embedded. If they are too close or touching, there will be a leakage of current from one to the other. The test is made in an instant by bringing the ends of the wires into contact with supply terminals. If the wires are defective a lamp lights up and gives effective warning of the fault. Similar appropriate tests are made during manufacture as the various components pass from one operation to the other; and also to the assembled lamps after each of the stages by which they approach completion.

Fig. 310.—Lead with Support Wires inserted.

After the supports are fixed the foot of the lamp is complete and ready for the filament. The latter has, however, to be prepared for mounting. Tungsten wire is not only very tough, but very easily tempered, and in the case of the ordinary vacuum lamp full advantage is taken of these good qualities in winding on the filament, which is formed in a zig-zag fashion from one set of supports to the other.

Before mounting, the wire is kinked at points which correspond to the bends at each support, this kinking being done in a machine known as the 'jazz' machine, because of its easy movement. Wire is unwound from the bobbins, as prepared in the wire-drawing department, and is caught up on a drum carrying two drums of small pegs. As the drum revolves the wire is 'jazzed' over one peg after another and is thus given a zig-zag shape; but if something were not done to 'set' it, it would go back to its original form when released. So, automatically, a current of electricity is sent for an instant through each limb of the wire while it is still on the pegs, thus annealing it and reconciling it permanently to its altered shape.

Emerging from the jazz machine, the wire is seen to be bent at regular intervals. So excellent is the temper of tungsten that the bends remain even after the wire is rewound on spools, unwound once more to pass through a bath which coats it with certain chemicals, and yet again rewound to be passed to the mounter. The actual mounting is still done by hand. As an operation, filament-mounting is perhaps not so troublesome as fixing supports, but to do it swiftly calls for a very high degree of skill. First the end of the filament is fastened to one leading-in wire; it is then wound up and down from one set of supports to the other; and lastly, it is fastened to the other leading-in wire and simultaneously cut off.

The 'fastening' referred to is done by the only piece of machinery the operator has to assist her. It is a power pincher, the jaws of which cut the tungsten wire and press the end right into the substance of the leading-in wire.

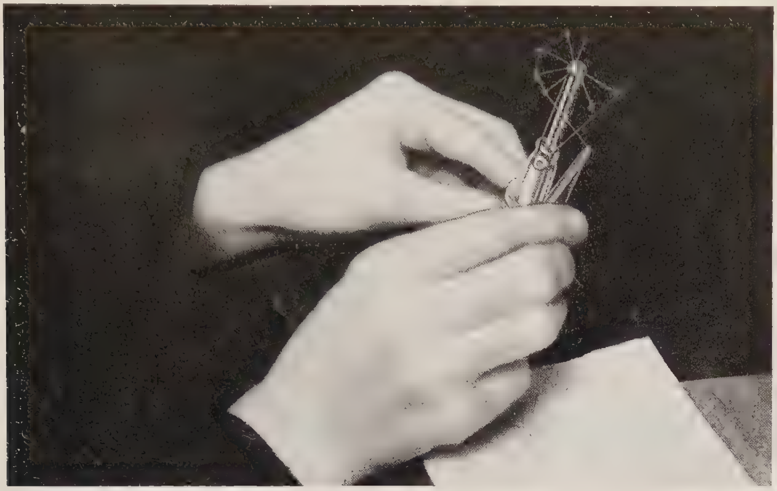

FIG. 311.—WINDING FILAMENTS ON SUPPORTS, GAS-FILLED LAMP.

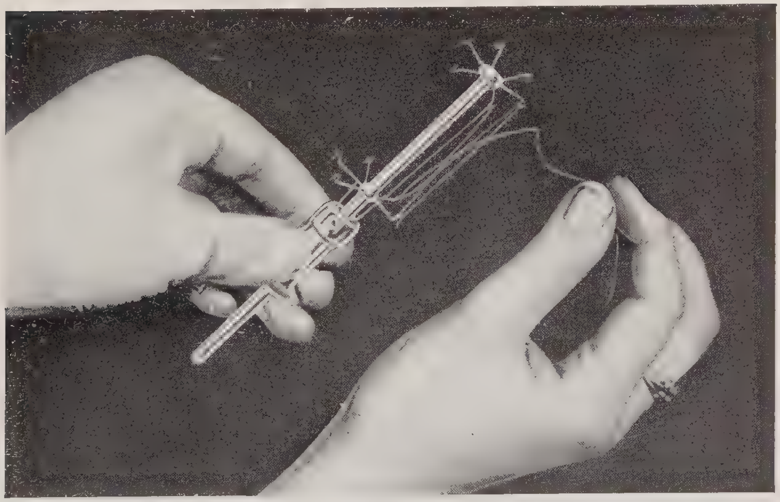

FIG. 312.—WINDING FILAMENTS ON SUPPORTS, VACUUM LAMP.

The whole process looks simple. The operator brings the leading-in wire and the filament together and actuates the pincher; the filament is then stringed as the foot turns round; and finally the pincher is brought into action again. These operations are done without haste, but also without wasting a single moment. A clever operator will perform the whole cycle of operations over two hundred and fifty times in an hour.

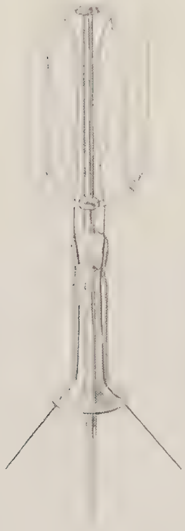

FIG. 313.—FILAMENTS WOUND UPON SUPPORTS AND CLAMPED TO LEADING-IN WIRES.

The next step, after the filament is mounted on the foot, is to mount the foot in the bulb. This is done in a machine in which the bulb is placed with its mouth hanging downwards over the foot; this is the position it will finally occupy in the lamp. What has to be done is to close the mouth of the bulb over the flanged end of the foot, and once more gas flames are called into play. They are concentrated on the glass, gradually melting it and blowing it inwards until it flows into contact with the foot and becomes one with it. The melting is done step by step, while the parts move round in a circle and each bulb is rotated to get a perfectly even effect. Finally, the excess portion of the neck, which has dropped by its own weight below the level of the foot, is cut off by finely pointed flames.

The succeeding stage is very important, and is known as 'exhausting,' and when this stage is reached the reason for the little tube which protrudes from the interior of the foot is realized. All the air has to be taken out of the lamp, and the tube is the passage through which it is withdrawn.

During exhaustion the lamps are enclosed in a heated chamber and connected to pumps which extract the air. A whole world of scientific invention has gone to the perfecting of the pumps and of every detail of creating the vacuum that nature is alleged to abhor. Incidental to the process, in the case of a vacuum lamp, is the use of a special substance, curiously called the 'getter,' which is applied as a coating on the filament before the latter is mounted.

In the process of exhaustion, as in many other processes in the making of lamps, automatic machinery has been developed. It is used for all standard sizes of lamps, and it carries out the whole process of exhausting and, if necessary, gas-filling, and sealing off by rotating machinery.

The operator pushes the exhaust tube of each lamp into a rubber bung. As each lamp moves round, a system of valves connects it successively to each of a series of vacuum pumps. While it is thus being exhausted it is heated by gas flames inside the metal hood to drive off the gases which cling tenaciously to its inner surfaces. By the time a lamp has made one circuit of the machine the exhaustion is complete, and it is sealed off automatically by a small two-flame

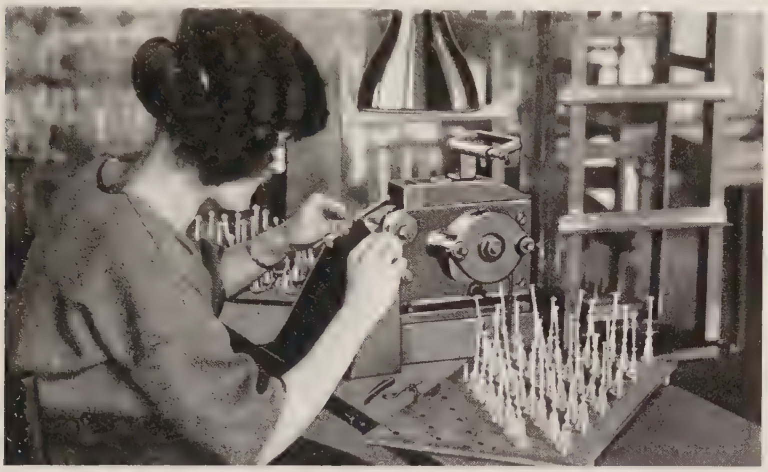

Fig. 314.—Clamping the Ends of the Filaments to the Leading-in Wires in the Power Pliers.

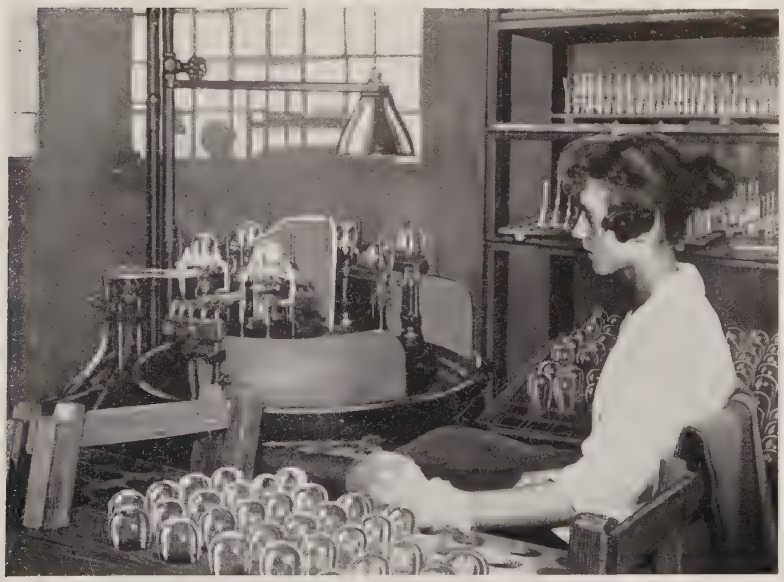

Fig. 315.—Assembling Bulbs and Filaments.

burner which melts off its exhaust tube, thus sealing it hermetically. So completely automatic is the process that even the piece of tube left in the rubber bung is removed mechanically to make room for a new lamp. Each lamp spends only 2½ minutes on the

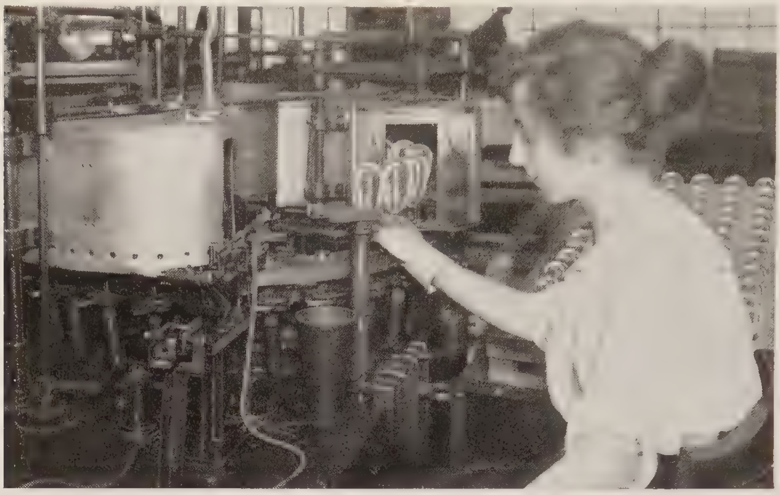

FIG. 316.—EXHAUSTING MACHINE.

FIG. 317.—SEALED-IN LAMP.

FIG. 318.—EXHAUSTED LAMP READY FOR CAPPING.

machine, which delivers exhausted bulbs at the rate of one every $5\frac{1}{2}$ seconds.

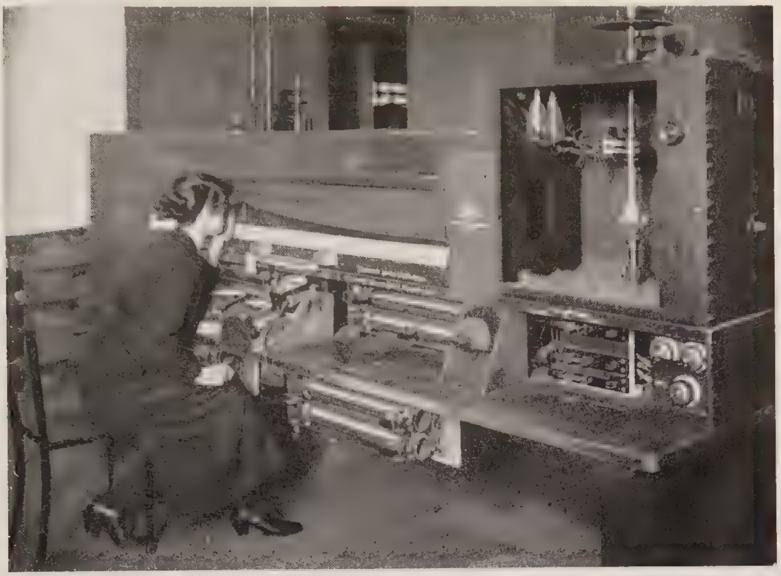

FIG. 319.—CHECKING CANDLE-POWER OF LAMP WITH A PHOTOMETER.

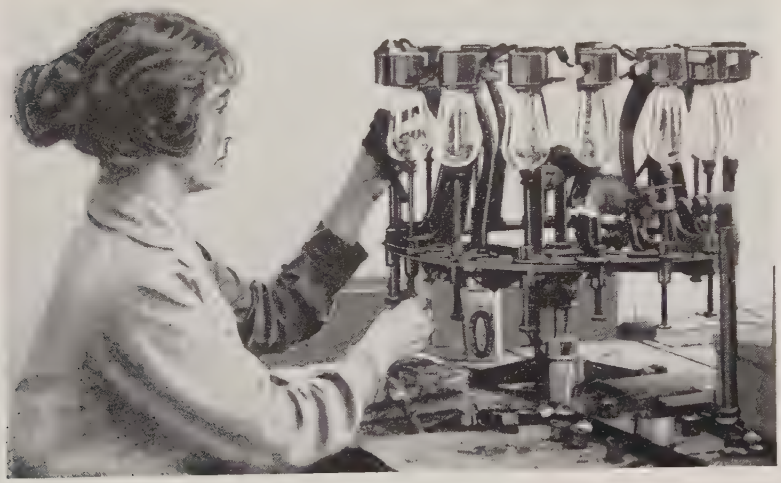

FIG. 320.—CAPPING MACHINE.

'Testing for vacuum' is carefully carried out for every lamp. In a darkened cupboard each bulb is subjected to an electrical discharge, and if any air remains it reveals its presence by a faint bluish glow.

This is in addition to a similar test applied on the exhausting machine itself, which ensures that every lamp, as it approaches the sealing-off point, exhibits the quality of its vacuum to the machine operator.

If we examine the lamp at this stage, we can understand a very important point about the leading-in wires. They are lines of communication between the air outside and the vacuum inside; all the rest is a continuous envelope of glass. Were the contact between the wires and the glass not absolutely close, were ever so tiny a passage left between the wires and the glass through which it runs, air would gradually leak into the bulb and destroy the vacuum.

It is essential, therefore, to find a wire which will not, in cooling, shrink away from the glass. Some metal must be chosen which will expand when being heated, and contract when cooling, at the same rate as the glass with which the bulb is made. This equal expansion and contraction must, moreover, be maintained all through the wide range of temperatures from that of molten glass to ordinary atmospheric temperatures.

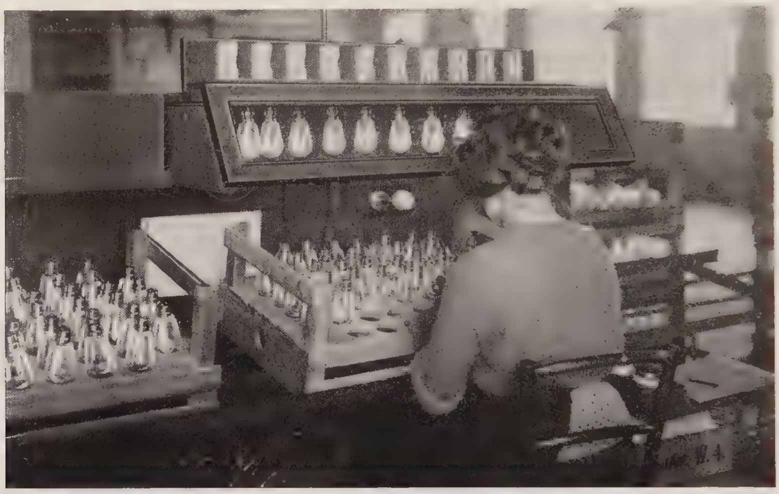

Fig. 321.—Final Testing.

Until recently, platinum was the metal generally used for this purpose. It worked admirably, but its cost is very high, which prohibits its use in large quantities. Lamp manufacturers, therefore, use nickel steel coated with copper, this being found to be quite suitable for the purpose.

The final stage in the actual manufacture of the lamp is known as 'capping,' and this is carried out on a circular-type stage-by-stage machine. A brass cap is filled with special cement and is placed on the top of the lamp, with the leading-in wires protruding through small holes in the metal segments which make contact when a lamp is placed in a lamp-holder. As the lamp moves round, the cement is baked hard by an electric heater, fixing the cap firmly to the bulb, and finally the protruding ends of the leading-in wires are cut off and a small quantity of solder put on to join them to the metal segments.

The only other operation to be performed before the lamp is placed in stock is 'testing.' This is done by means of a photometer, an instrument which may be termed a light-measurer; it is designed to give immediate accurate results. The instrument depends upon balancing the light of the lamp under test against the light of a standard lamp. Simultaneously with candle-power the current taken by each lamp is noted. These two items—light and energy consumption—form the basis upon which lamps are classified.

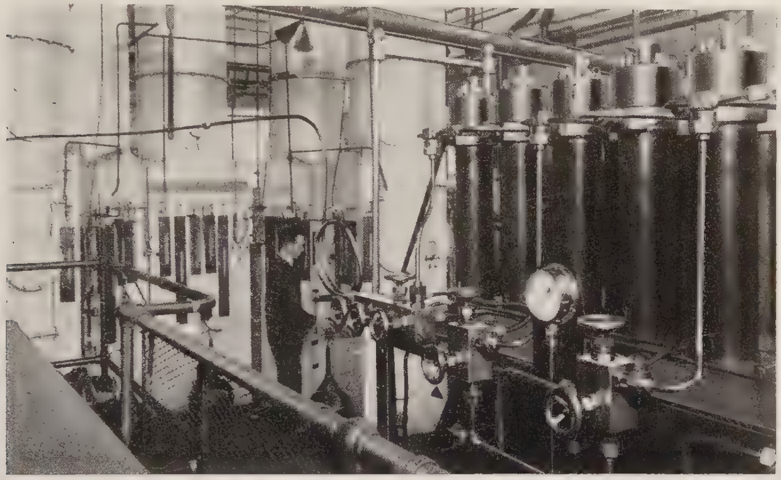

FIG. 322.—VIEW OF ARGON GAS PLANT.

The vacuum lamp may be considered as the parent of the modern gas-filled lamp, since the production of the latter is the result of experience gained with the former. There are many differences, however, between the two lamps, the most important one being, of course, that one lamp contains vacuum, while the other is filled with an invisible gas.

The effect of introducing an inert gas, such as nitrogen or argon, into the bulb of an incandescent electric lamp is:

1. To cool the filament.
2. To reduce the rate of filament evaporation.

The maximum efficiency (or minimum watts per candle-power) at which a lamp is capable of being run is limited by the temperature at which the filament can be maintained; other things being equal, the higher the temperature the greater the efficiency. The temperature to which the tungsten filament can be heated is limited by the filament evaporation. Evaporation sets a limit to the permissible temperature, partly because eventually it causes the filament to break, but more particularly because the evaporated substance is deposited on the bulb and, being opaque, obscures the light.

The function of the gas in a gas-filled lamp is to prevent the evaporation of the filament and accordingly make possible the use of higher temperatures, without either accelerating the blackening or shortening the life of the lamp. The gas, however, operates to cool the filament by taking energy from the wire in the form of heat and carrying it wastefully to the walls of the bulb. In order to make the gas-filled lamp more efficient than the vacuum lamp, it is necessary that the gain in efficiency obtained by raising the temperature of the filament should exceed the loss due to this cooling effect.

To fulfil this requirement the filament must be comparatively thick—indeed, much thicker than is practicable for ordinary commercial lamps; and since the length and diameter of the tungsten filament for a lamp of given candle-power and voltage are unalterable, it would seem impossible to achieve this result.

This difficulty, however, is overcome by an ingenious device. The relation between the thickness and the resistance of any filament, which leads to the difficulty, holds only so long as the current flows straight along the filament; if it could be made to flow in the same filament along a much longer path, the resistance would be increased but the surface would be unchanged. This result is effected by making the filament a closely wound spiral of very fine wire, which, in respect of light emission and heat loss in the gas, acts almost as if it were a short wire of the same thickness as the external diameter of the spiral, whilst still having the high resistance of a long, thin wire.

A further effect of introducing gas is to convey the evaporated particles to the top of the bulb. For this reason the bulb is of a special shape to offer considerable cooling surface to the hot gas rising from the filament, whilst the small amount of evaporated tungsten is deposited where the slight blackening does not obscure the light. Broadly, the making of a gas-filled lamp follows the same lines as that of a vacuum lamp, with additional processes which are peculiar to the former.

The first is the winding of the straight wire into the spiral. Originally this was done by hand, but, later, machines were developed to do the business more rapidly and accurately. In these machines a bobbin carrying tungsten wire revolves round a straight wire which acts as a mandril; as the mandril travels slowly along, the tungsten wire forms a spiral round it.

During the manufacture of filaments for large gas-filled lamps it will be noticed that at short intervals there is a pause in the process. During each of these intervals the wire is not spiralled, so that in the end there is, not a continuous spiral, but a series of spiral lengths joined by short, straight sections. When the winding is completed, the wire is carefully drawn off the mandril.

The reason for this is seen as the process proceeds. The spiral filament is mounted in a horizontal circle which, in some of the large lamps, is zig-zagged to get more wire into the circle. Looking at such a lamp closely, we see that the supports hold the filament at the straight pieces, the spirals running from support to support.

It is only in the larger gas-filled lamps, however, where the filaments are comparatively thick and heavy, that the mounting is done in this way. The smaller lamps, such as are used for domestic lighting, have a continuous spiral. This is so thin and fine that it could not be drawn off the mandril without stretching the spiral and spoiling the perfect evenness which is needed to make a satisfactory filament. In order to get over this difficulty, a very ingenious device is used. The filament is wound upon a thin wire of soft brass; and after completion the whole is immersed in a bath of nitric acid, which dissolves out the brass and leaves the spiral of tungsten wire unaffected.

At the next stage the spiral is cut into lengths, each length being the exact size for mounting in a lamp. In order to make quite sure that each length is perfect and contains the correct length of wire, it is weighed in a very sensitive balance, and any length which is too light or too heavy is rejected.

The mounting is done very much in the same way as with a vacuum lamp, the wire being hung on the supports. There is, however, only one set of supports, and stout nickel wires are used to connect the ends of the filament with the copper-clad leading-in wires in the glass stem. This connection is made by electric welding, an operation taking only a fraction of a second.

One would imagine that, as the bulb is to be filled with gas in any case, little trouble need be taken about obtaining a perfect vacuum in making a gas-filled lamp. The truth, nevertheless, is very much otherwise, and, paradoxically enough, a good vacuum is even more essential for a gas-filled lamp than for a vacuum lamp. Particular care is therefore taken to extract all the air and other gases after the stem and bulb have been assembled. When an excellent vacuum has been obtained, a mixture of pure argon and nitrogen gas is introduced into the bulb by a modification of the valve gear mentioned in the description of the exhausting machine. The presence of this gas in a lamp bulb enables the filament to be run extremely hot. The filament heats the argon, making it rise to the upper parts of the lamp, where it is cooled and descends again, keeping up this circulation continuously.

In the larger gas-filled lamps it will be seen that a transparent disc of mica surrounds the stem. This disc acts as a baffle to the rising current of hot argon, and prevents overheating of the glass surrounding the leading-in wires, which, since glass loses its insulating properties very rapidly as its temperature rises, would otherwise be liable to electrolytic decomposition by current passing between the wires embedded in its substance.

When the gas-filled lamp first came into existence it was made only in large sizes. Now it is produced in sizes ranging from 10,000 candle-power down to lamps suitable for domestic lighting. It is also made in many special forms for cinematograph projectors, optical purposes, motor-car headlights, etc.

BRITISH STANDARD SPECIFICATION No. 161—1924

FOR

NORMAL-TYPE TUNGSTEN-FILAMENT ELECTRIC LAMPS[1]

Published by permission of the British Engineering Standards Association,
28 Victoria Street, London, S. W.

A. STANDARDS AND DEFINITIONS

Normal-Type Lamps are lamps the construction of which conforms to this specification and which are of the voltage, dimensions, and sizes included in the appropriate Schedules.

The *Candle* is the unit of luminous intensity. For the purposes of this Specification it is the International Candle as defined by the International Commission on Illumination as follows :—

> 'The International Candle is the international unit of luminous intensity, such as resulted from agreements effected between the three National Standardizing Laboratories of France, Great Britain, and the United States, in 1909.[2]
>
> 'This unit has been maintained since then by means of incandescent electric lamps in these laboratories, which continue to be entrusted with its maintenance.'

Secondary Standards for use in Great Britain are suitable lamps which have been certified by the National Physical Laboratory and the candle-power of which at the time of use is in agreement with the value obtained at the National Physical Laboratory.

Candle-Power is the luminous intensity expressed in Candles.

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[1] Copies of this Specification can be had from the British Engineering Standards Association, 28 Victoria Street, London, S.W. Price 1s. net, 1s. 2d. post free.

[2] These Laboratories are :—The Laboratoire Central d'Électricité in Paris, the National Physical Laboratory at Teddington, and the Bureau of Standards in Washington.

The *Lumen* is the unit of luminous flux. It is equal to the flux emitted in unit solid angle by a uniform point source of one international candle.

NOTE.—A *Lumen* is the total amount of light intercepted by or falling upon a surface of one square foot, every point of which is at a distance of one foot from a point light source of one candle. The total flux emitted from a uniform light source of one candle is 4π (=12·57) lumens.

The *Mean Spherical Candle-Power* of a lamp is the average value of the candle-power in all directions.

The *Efficiency* is the ratio of the luminous output to the input of power. It is expressed in lumens per watt.

The *Rated Volts and Watts* are the volts and watts marked by the manufacturer on the lamp.

The *Rated Amperes* are the amperes marked by the manufacturer on the lamp. This term is applied only to lamps of the series-burning type.

The term *Type* is used to denote lamps of the same general construction or which are designed for special service.

The term *Class* is used to denote lamps of the same type which are identical in rating.

The term *Batch* denotes all the lamps of one class put forward at one time for acceptance.

The *Light-Centre Length* is the distance from the geometrical centre of the filament to the sole-plate of the cap.

The *Life* of a lamp is the number of hours run to ‘ burn-out.’

The *Average Life* is the arithmetical mean of the lives of the lamps in a Life Test Quantity.

The *Specified Life* of a lamp is the life in hours given in the appropriate Schedule.

The *Lumen or Candle Maintenance for an Individual Lamp* is the average of its lumens or candles throughout its life test, expressed as a percentage of its initial lumens or candles.

The *Lumen or Candle Maintenance for any Test Quantity of Lamps* is the total of the lumen- or candle-hours throughout the life test of all the lamps divided by the total of the hours of life thereof, the result being expressed as a percentage of the initial lumens or candles.

The *Average Efficiency throughout Life for an Individual Lamp* is the ratio of the total lumen-hours to the total watt-hours expressed in terms of lumens per watt, or the ratio of the total watt-hours to the total candle-hours expressed in terms of watts per candle.

The *Average Efficiency throughout Life for any Test Quantity of Lamps* is the ratio of the total of the lumen-hours of all the lamps to the total watt-hours thereof, expressed in terms of lumens per watt, or the ratio of the total watt-hours of all the lamps to the total candle-hours thereof, expressed in terms of watts per candle.

The *Inspection Quantity* consists of sample lamps selected for the purpose of determining the acceptability of a batch of lamps as to mechanical and physical requirements.

The *Rating Test Quantity* consists of sample lamps selected for the purpose of determining the acceptability of a batch of lamps as to initial rating.

The *Life Test Quantity* consists of sample lamps selected for the purpose of determining the acceptability of a batch of lamps as to life, efficiency, and lumen or candle maintenance.

B. SPECIFICATION

NOTE.—This Specification covers Normal-Type Tungsten-Filament Electric Lamps with clear uncoloured glass bulbs, the lamp ratings, bulb shape, and cap being those recognized as standard for the various types.

The basis for comparison of the light-giving power of all lamps referred to in this Specification is the lumen or the mean spherical candle as defined by the International Commission on Illumination.

SECTION I—REQUIREMENTS

British Standard Electric Lamps.

1. British Standard Electric Lamps shall conform to the requirements of this Section of the Specification when tested in accordance with the requirements of Section II.

Bulbs.

2. The bulbs shall be uniform in size and shape, clear, clean, and free from colour, flaws, or blemishes detrimental to service.

Caps.

3. (*a*) The caps shall be accurately fitted and securely attached to the bulbs with a suitable cement, so that they shall not become loose with reasonable usage during life. The shell of the cap shall be of brass or other suitable material.

(*b*) The contact plates of the caps shall be of brass or copper and shall be suitably fixed to the shell of the cap by means of vitreous or ceramic insulating material.

(*c*) The bayonet cap shall have the dimensions given in Appendix II.

(*d*) The Edison and Goliath Edison screw cap shall have the dimensions given in Appendix III.

(NOTE.—The dimensions for the Edison screw cap are not yet settled.)

(*e*) The attachment of cap to bulb shall be of sufficient strength to withstand a torsion test as indicated in Table I of the appropriate Schedule.

Leading-in Wires.

4. Leading-in wires shall be attached to the cap without excess of solder; in the case of screw caps the threads shall be entirely free from solder.

Filament.

5. All portions of the filament between the points of support shall be uniform in appearance both at rated and half voltages.

Dimensions of Lamps.

6. The dimensions of the lamps shall be in accordance with the values given in Table I of the appropriate Schedule.

Light-Centre Lengths.

7. The light-centre lengths (where specified) shall be in accordance with the values given in Table I of the appropriate Schedule.

Lamp Marking.

8. Every lamp shall be indelibly and distinctly marked with the following information :—

(*a*) The rated voltage, and in the case of series-burning lamps the rated current.

(*b*) The rated watts.

(*c*) The manufacturer's name and/or trade-mark.

Insulation Resistance.

9. The insulation resistance between the shell of the bayonet cap and filament shall not be less than 50 megohms.

Limits of Variation in Initial Lumens.

10. The initial lumens or candle-power of the lamps shall fall within the values given in Table II of the appropriate Schedule when the rated voltage is applied to the lamp, and in the case of series-burning lamps when the rated current is passing through the lamp.

Limits of Variation in Initial Watts.

11. The initial watts shall fall within the values given in Table II of the appropriate Schedule when the rated voltage is applied to the lamp, and in the case of series-burning lamps when the rated current is passing through the lamp.

Limits of Variation in Efficiency.

12. The initial lumens per watt, or the initial watts per mean spherical candle, shall fall within the values given in Table II of the appropriate Schedule when the rated voltage is applied to the lamp, and in the case of series-burning lamps when the rated current is passing through the lamp.

Limits of Variation in Initial Rated Volts of Series-Burning Lamps.

13. The initial rated volts of series-burning lamps shall fall within the values given in Table II of the appropriate Schedule when the rated current is passing through the lamp.

Life Performance.

14. The average life, the average efficiency throughout life, and the lumen or candle maintenance shall not vary from the values given in Table III of the appropriate Schedule by more than the allowances given in Table IV of the same Schedule, the results being computed in accordance with Section II of this Specification.

SECTION II—TESTING

NOTE.—Agreement should be reached before the order is placed in regard to the carrying out of tests for compliance with this Specification. Usually the purchaser arranges for the carrying out at his own expense of the life tests, the manufacturer providing facility for the selection by the purchaser of all test quantities of lamps, and also facilities for the other tests.

Selection and Testing of Lamps for Mechanical, Electrical, and Physical Defects.

15. (*a*) When all the lamps in a batch are tested for limiting dimensions, mechanical, electrical, and physical defects, all which do not comply with Clauses 2 to 9 shall be deemed not to have satisfied the requirements of this Specification, and should more than 25 per cent. of any batch of lamps fail to comply with these Clauses the whole of the batch of lamps shall be deemed not to comply with this Specification.

(*b*) When all the lamps in a batch are not tested in accordance with (*a*), an 'Inspection Quantity,' which shall consist of not less than five per cent. from each batch it is desired to inspect, shall be selected as follows, the quantity so selected being in no case less than 25 lamps :—

From Unpacked Lamps.

At random.

From Packed Lamps.

I. For batches containing 1000 lamps or less :—
  (i) When packed in boxes of 100 lamps or more—an approximately equal number of lamps from each box.
  (ii) When packed in boxes of less than 100 lamps—an equal number of lamps from each of at least one-half of the boxes.

II. For batches containing more than 1000 lamps :—
  An equal number of lamps from each of at least one-third of the boxes.

Should any lamp of the Inspection Quantity fail to pass the requirements of Clauses 2 to 9 (mechanical, electrical, and physical defects), it shall be deemed not to have satisfied the requirements of this Specification; and should more than 25 per cent. of the Inspection Quantity fail to pass the requirements, the whole batch of lamps represented by the Inspection Quantity shall be deemed not to comply with this Specification.

The test for insulation resistance between cap and filament shall be made at the works of the manufacturer. In cases in which it is desired to make an insulation test after delivery, the conditions and details of such test shall be subject to special arrangement.

Selection and Testing of Lamps for Initial Watts and Lumens or Mean Spherical Candle-Power.

16. A 'Rating Test Quantity' of lamps shall be selected in a similar manner to the selection of the Inspection Quantity (see Clause 15 (*b*)), the total number in the Rating Test Quantity to be 25 lamps in the case of batches of 500 lamps or less, and thereafter five per cent. of the total batch represented by the Rating Test Quantity.

The lamps selected for the Inspection Quantity may be used provided they have satisfied the inspection test.

The lamps in the Rating Test Quantity shall have been aged for the period given, and at the voltage specified in Table II of the appropriate Schedule; the lamps shall be tested at rated volts, or in the case of series-burning lamps, at rated current for compliance with the requirements of Clauses 10, 11, 12, and 13.

Should more than one-twentieth of the Rating Test Quantity plus two lamps [1] fail to pass the requirements of Clauses 10, 11, 12, and 13, the batch represented by the Rating Test Quantity shall be deemed not to comply with this Specification.

Selection of Life Test Quantity.

17. (*a*) For the purpose of the Life Performance Test, a 'Life Test Quantity' shall be selected, to represent any one batch of lamps, of not less than 20 per cent. of the lamps forming the Rating Test Quantity, and in no case less than five lamps.

(*b*) If the average life, the mean lumens or candles, and mean lumens per watt or watts per candle throughout the life of the lamps vary from the values given in Table III of the appropriate Schedule by more than the allowances given in Table IV of the same Schedule, all lamps of the batch represented by the Life Test Quantity shall be deemed not to comply with this Specification.

In the case of lamps being accidentally broken before the life test is completed, the results shall be calculated from the performance of the lamps which have completed the test. The batch of lamps from which such Life Test Quantity was selected shall not be deemed to have failed under this Specification until sufficient additional lamps to make up the minimum number required by paragraph (*a*) have completed the test without accidental breakage.

(*c*) If the filament of a lamp breaks during handling, such a lamp shall be counted as having been accidentally broken.

Test for Life, Lumen or Candle Maintenance, and Average Efficiency throughout Life.

18. Life tests on lamps shall be carried out under the following conditions :—

(*a*) *Test Voltage.*—Each lamp in the Life Test Quantity shall be run throughout the life test in the position specified in Table III of the appropriate Schedule, and at the voltage which causes the initial lumens per watt or watts per candle to be equal to the rated value for that type and rating given in Table II of the appropriate Schedule.

The momentary fluctuations from the test voltage during the life test shall not exceed plus or minus one per cent., and there shall be no sensible departure of the mean value of the life test voltage from its correct value.

Accurate records shall be obtained throughout the life test by a recording voltmeter to show the variation of the voltage on the circuit.

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[1] NOTE.—In the case of a fraction resulting from this calculation the next highest whole number shall be taken.

By mutual arrangement, the lamps may be run at the rated voltage provided that the initial efficiency of each lamp at that voltage is within two per cent. of the rated value given in Table II of the appropriate Schedule, and that the average efficiency of all lamps run is in no case better than the rated value.

(*b*) *Measurements during Life Test.*—Each lamp in the Life Test Quantity shall be measured for mean spherical candle-power and watts at the rated voltage at the end of intervals of approximately 0, 10, 20, 30, 50, 75 per cent. of the specified life, and thereafter at intervals of approximately 25 per cent. of the specified life until the lamp fails.

(*c*) *Duration of Life Test.*—The lamps shall be run until the average life attains the value given in Table III of the appropriate Schedule, or until the average lumen or candle maintenance just falls below the value given in the same Table (subject to the appropriate allowance), whichever period is the shorter.

To provide for the early elimination from the test of an abnormal lamp which may show a relatively sudden and marked decline in light output, any lamp shall be considered to have burnt out when its light output passes below 60 per cent. of its initial light output.

(*d*) *Lamp Failures.*—A record shall be kept of the number of lamp failures and of the number of hours run by each lamp before failure.

Computation of Results of Life Performance.

19. (*a*) *Average Life.*—The average life of the batch of lamps represented by the Life Test Quantity shall be the arithmetical mean of the lives of the lamps in the Life Test Quantity.

(*b*) *Lumen or Candle Maintenance of a Batch of Lamps.*—The lumen or candle maintenance of the batch of lamps represented by the Life Test Quantity shall be calculated from the formula

$$\frac{A}{B}100,$$

where

A=the sum of the lumen- (or candle-) hours of all lamps in the Life Test Quantity divided by the sum of the hours of life thereof, and
B=the arithmetical mean of the initial lumens (or candles) of these lamps.

(*c*) *Average Efficiency throughout Life of a Batch of Lamps.*—The sum of the lumen-hours (or candle-hours) and the sum of the watt-hours of all the lamps in the Life Test Quantity shall be calculated.

The average efficiency throughout life in terms of lumens per watt is the total lumen-hours divided by the total watt-hours; or the average efficiency throughout life in terms of watts per candle is the total watt-hours divided by the total candle-hours. (See Appendix I.)

(*d*) The lumen- (or candle-) hours or the watt-hours shall be calculated on the assumption that the change in lumens (or candles) or watts follows a straight-line law between the respective values for the tests.

SCHEDULE FOR NORMAL-TYPE VACUUM TUNGSTEN-FILAMENT LAMPS

TABLE I

DIMENSIONS

NOTE.—Millimetre dimensions are to be regarded as standard.

Rating		Standard Caps	Maximum Over-all Dimensions			
Volts	Watts		Length		Bulb Diameter	
1	2	3	4		5	
			mm.	in.	mm.	in.
100 to 130	10	B.C.	122	4·8	61	2·4
100 to 130 and 200 to 260	20	B.C.	140	5·5	63	2·5
	30	,,	140	5·5	63	2·5
	40	,,	140	5·5	63	2·5
	60	,,	150	5·9	70	2·75

TABLE II

INITIAL RATING

Rated Volts	Rated Watts	Initial Total Watts		Initial Efficiency						Initial Lumens and Candles						Ageing Period (see Clause 16)	Rated Volts
		Max.	Min.	Lumens per Watt			Watts per Mean Spherical Candle			Lumens			Mean Spherical Candles				
				Rated	Max.	Min.	Rated	Max.	Min.	Rated	Max.	Min.	Rated	Max.	Min.		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1
	10	12	8	7·67	8·27	7·06	1·65	1·78	1·52	75	88	63	6	7	5	One	
100	20	23	17	8·70	9·24	8·16	1·45	1·54	1·36	174	195	151	14	16	12	Hour	100
to	30	33	27	9·20	9·75	8·65	1·38	1·47	1·29	273	308	239	22	25	19	at	to
130	40	44	36	9·32	9·90	8·73	1·36	1·44	1·27	370	413	327	29	33	26	Rated	130
	60	66	54	9·49	10·05	8·92	1·33	1·41	1·25	567	641	497	45	51	40	Volts	
200	20	23	17	7·67	8·27	7·06	1·65	1·78	1·52	152	176	132	12	14	11	One Hour	200
to	30	33	27	8·24	8·77	7·70	1·53	1·63	1·43	246	277	214	20	22	17	at	to
260	40	44	36	8·70	9·24	8·16	1·45	1·54	1·36	347	390	302	28	31	24	Rated	260
	60	66	54	9·20	9·75	8·65	1·38	1·47	1·29	547	616	478	44	49	38	Volts	

TABLE III

LIFE PERFORMANCE

Position of Burning	Rated Volts	Rated Watts	Average Efficiency throughout Life		Lumen or Candle Maintenance (Average Lumens or Candles throughout Life expressed as a percentage of initial Lumens or Candles)	Average Life (Burn-out)
			Lumens per Watt	Watts per Mean Spherical Candle		
1	2	3	4	5	6	7
Pendant position, Vertical.	100 to 130	10	7·39	1·7	96	1000
		20	8·16	1·54	94	1000
		30	8·38	1·5	92	1000
		40	8·38	1·5	90	1000
		60	8·38	1·5	90	1000
Pendant position, Vertical.	200 to 260	20	7·39	1·7	95	1000
		30	7·76	1·62	94	1000
		40	8·06	1·56	92	1000
		60	8·27	1·52	90	1000

TABLE IV

PERCENTAGE ALLOWANCES ON LIFE PERFORMANCE

Number of Lamps in Life Test Quantity	Allowable Variation from Specified Value		
	Life	Average Efficiency	Lumen or Candle Maintenance
1	2	3	4
5	25 per cent.	5 per cent.	4 per cent.
6	23 per cent.		
7	21 per cent.		
8	20 per cent.		
9	19 per cent.		
10	18 per cent.	4 per cent.	3 per cent.
11	17 per cent.		
12 or 13	16 per cent.		
14 or 15	15 per cent.		
16 or 17	14 per cent.		
18 or 19	13 per cent.		
20 to 24	12 per cent.		
25 to 29	11 per cent.	3 per cent.	2 per cent.
30 to 34	10 per cent.		
35 to 44	9 per cent.		
45 to 54	8 per cent.		
55 to 99	7 per cent.		
100 to 249	6 per cent.	2 per cent.	1 per cent.
250 or more	5 per cent.		

SCHEDULE FOR NORMAL-TYPE GAS-FILLED LAMPS

TABLE I

DIMENSIONS

NOTE.—Millimetre dimensions are to be regarded as Standard.

Rating		Standard Caps	Maximum Over-all Dimensions						Light-Centre Length with Standard Cap. Tolerance ± 10 per cent. with max. of 10 mm.		Torsion Test for Bayonet and Edison and Goliath Edison Screw Cap	
Volts	Watts		Length		Diameter of Bulb		Diameter of Neck				Bayonet and Edison	Goliath
1	2	3	4		5		6		7		8	9
			mm.	inches (approx.)	mm.	inches (approx.)	mm.	inches (approx.)	mm.	inches (approx.)		
100 to 130	30	B.C.	120	4·7	62	2·4	35	1·4	80	3·2	25 pound-inches	45 pound-inches
100 to 130 and 200 to 260	40	B.C.	125	4·9	62	2·4	35	1·4	85	3·4		
	60	,,	125	4·9	72	2·8	*40	1·6	85	3·4		
	75	,,	150	6·0	72	2·8	*40	1·6	100	4·0		
	100	,,	170	6·7	82	3·2	*42	1·7	120	4·8		
	150	,,	170	6·7	92	3·6	45	1·8	120	4·8		
	150	E.S.	180	7·1	92	3·6	45	1·8	130	5·2		
	200	,,	215	8·5	103	4·1	48	1·9	150	5·9		
	300	G.E.S.	250	9·9	113	4·5	55	2·2	180	7·1		
	500	,,	280	11·1	133	5·3	†60	2·4	205	8·1		
	1000	,,	340	13·4	173	6·8	70	2·8	250	9·9		
	1500	,,	340	13·4	173	6·8	70	2·8	250	9·9		

* It is intended to reduce this dimension to 38 mm. as soon as possible.
† It is intended to reduce this dimension to 57 mm. as soon as possible.

TABLE

INITIAL

Rated Volts	Rated Watts	Initial Total Watts		Initial Efficiency					
				Lumens per Watt			Watts per Mean Spherical Candle		
		Max.	Min.	Rated (see Clause 18)	Max.	Min.	Rated (see Clause 18)	Max.	Min.
1	2	3	4	5	6	7	8	9	10
100 to 130	30	34	25·5	To be declared by the Manufacturer	10·6	7·95	To be declared by the Manufacturer	1·58	1·19
	40	46	34·5		11·4	8·55		1·47	1·10
	60	69	51		12·8	9·6		1·31	0·98
	75	83	67		13·4	10·0		1·25	0·94
	100	110	90		14·6	10·9		1·15	0·86
	150	165	135		15·3	11·4		1·10	0·82
	200	220	180		15·9	12·0		1·05	0·79
	300	330	270		16·5	12·5		1·01	0·76
	500	550	450		18·7	14·0		0·90	0·67
	1000	1100	900		20·0	15·0		0·84	0·63
	1500	1650	1350		20·0	15·0		0·84	0·63
200 to 260	40	46	34		8·85	6·65		1·89	1·42
	60	69	51		10·6	7·95		1·58	1·19
	75	83	67		11·4	8·6		1·46	1·10
	100	110	90		12·8	9·6		1·31	0·98
	150	165	135		13·4	10·0		1·26	0·94
	200	220	180		14·6	10·9		1·15	0·86
	300	330	270		15·3	11·4		1·10	0·82
	500	550	450		16·5	12·5		1·01	0·76
	1000	1100	900		18·7	14·0		0·90	0·67
	1500	1650	1350		19·3	14·5		0·87	0·65

II

RATING

Initial Lumens and Candles						Ageing Period (see Clause 16)	Rated Volts
Lumens			Mean Spherical Candles				
Approx. Rated Lumens	Max.	Min.	Approx. Rated Candle-power	Max.	Min.		
11	**12**	**13**	**14**	**15**	**16**	**17**	**1**
275	327	218	22	26	18	One hour at rated volts	100 to 130
390	469	311	32	38	25		
660	791	527	53	63	42		
875	1050	700	70	84	56		
1250	1440	1060	100	115	85		
1970	2260	1670	157	180	133		
2730	3140	2320	218	250	185		
4260	4900	3620	339	390	288		
8000	9200	6800	637	732	542		
17100	19700	14500	1360	1565	1155		
25700	29600	21800	2043	2350	1735		
305	365	243	24	29	19	One hour at rated volts	200 to 260
545	654	436	44	52	35		
750	905	590	60	72	47		
1100	1320	880	88	105	70		
1720	1970	1460	137	157	116		
2510	2880	2130	200	230	170		
3930	4520	3340	313	360	266		
7110	8170	6040	565	650	480		
16000	18400	13600	1273	1465	1080		
24830	28550	21100	1975	2270	1680		

TABLE III

LIFE PERFORMANCE

Position of Burning	Rated Volts	Rated Watts	Average Efficiency throughout Life		Lumen or Candle Maintenance (Average Lumens or Candles throughout Life expressed as a percentage of initial Lumens or Candles)	Average (Arithmetical Mean) of the Lives to burn out
			Lumens per Watt	Watts per Mean Spherical Candle		
1	2	3	4	5	6	7
Pendant position, Vertical.	100 to 130	30	8·4	1·50	85	1000
		40	9·0	1·40	85	1000
		60	10·1	1·25	85	1000
		75	10·5	1·20	85	1000
		100	11·4	1·10	87	1000
		150	12·0	1·05	87	1000
		200	12·6	1·00	90	1000
		300	13·1	0·96	90	1000
		500	14·6	0·86	90	1000
		1000	15·7	0·80	90	1000
		1500	15·7	0·80	90	1000
Pendant position, Vertical.	200 to 260	40	7·1	1·8	80	1000
		60	8·4	1·50	85	1000
		75	9·00	1·40	85	1000
		100	10·1	1·25	85	1000
		150	10·5	1·20	85	1000
		200	11·4	1·10	87	1000
		300	12·0	1·05	87	1000
		500	13·1	0·96	90	1000
		1000	14·6	0·86	90	1000
		1500	15·2	0·83	90	1000

TABLE IV

PERCENTAGE ALLOWANCES ON LIFE PERFORMANCE

Number of Lamps in Life Test Quantity	Allowable Variation from Specified Value		
	Life	Average Efficiency	Lumen or Candle Maintenance
1	2	3	4
5	25 per cent.	5 per cent.	4 per cent.
6	23 per cent.		
7	21 per cent.		
8	20 per cent.		
9	19 per cent.		
10	18 per cent.	4 per cent.	3 per cent.
11	17 per cent.		
12 or 13	16 per cent.		
14 or 15	15 per cent.		
16 or 17	14 per cent.		
18 or 19	13 per cent.		
20 to 24	12 per cent.		
25 to 29	11 per cent.	3 per cent.	2 per cent.
30 to 34	10 per cent.		
35 to 44	9 per cent.		
45 to 54	8 per cent.		
55 to 99	7 per cent.		
100 to 249	6 per cent.	2 per cent.	1 per cent.
250 or more	5 per cent.		

APPENDICES

APPENDIX I—EXAMPLE OF COMPUTATION OF RESULTS OF LIFE PERFORMANCE

Note.—To facilitate computation of life performance results the following case has been worked out in full. (It is recognized that there are other ways of arriving at these results.)

The tests for lumens or mean spherical candle-power and watts are made at approximately 0, 10, 20, 30, 50, 75, 100, and 125 . . . per cent. of the specified life.

The following Tables show the results of the tests and the methods of arriving at the life, lumen (or candle) maintenance, and average efficiency throughout life for a Life Test Quantity of lamps.

Table A

Test Results for Individual Lamp No. 1 (40-*watt*, 110-*volt gas-filled*) *of a Life Test Quantity of* 10 *Lamps*

1	2	3	4	5	6	7	8
Hours from commencement of test	Measured Lumens	Average Lumens for each period	Length of each period in hours	Lumen-hours for each period. Col. 3 × Col. 4	Measured Watts	Average Watts for each period	Watt-hours for each period. Col. 7 × Col. 4
0	470 (initial value)	...	...	...	44·5	...	...
110	455	463	110	50930	44·5	44·5	4900
197	449	452	87	39320	44·4	44·45	3860
306	441	445	109	48510	44·4	44·4	4840
504	427	434	198	85930	44·3	44·35	8800
729	412	420	225	94500	44·2	44·25	9950
1015	398	405	286	115830	44·2	44·2	12650
Totals .	...	...	1015	435020	...	...	45000

The results of the tests of the other 9 lamps would be set out in a similar manner. Only the initial value of lumens and the totals shown are required for the final computation. These, together with similar figures for the 9 other lamps in the Life Test Quantity, are carried to Table B, shown on the next page.

NOTE.—The following Table gives a summary taken from a series of test results similar to the example already given for the individual lamp (see Table A), together with the necessary calculations to ascertain if the Life Test Quantity has satisfied the requirements of the specification.

TABLE B

Collected Test Results of Life Test Quantity of 10 *Lamps*

(Lamp No. 1 of this Table is taken from Table A)

1	2	3	4	5	6
Lamp No.	Life (Period of test in hours)	Initial Lumens	Total Lumen-hours	Total Watt-hours	Average Lumens
1	1015	470	435020	45000	Average Lumens = Total of Col. 4 divided by Total of Col. 2
2	1015	430	395460	43640	
3	1015	431	392820	41720	
4	810	440	310120	30970	
5	1015	405	340550	40600	
6	1015	398	338040	40290	
7	930	431	362410	36640	$\frac{3651610}{9735}$
8	890	462	378120	32040	$= 375$
9	1015	401	340550	37760	
10	1015	405	358520	42120	
Totals	9735	4273	3651610	390780	
	Average Life = 9735 ÷ 10 = 973·5 (1000 hrs. specified, *see* Schedule) Allowable variation 18% (*see* Schedule) The Average Life is therefore up to standard.	Average Initial Lumens = 4273 ÷ 10 = 427	Average Efficiency throughout Life (lumens per watt) $= \frac{3651610}{390780} = 9·34$ Lumen Maintenance $= \frac{375}{427} \times 100 = 87·8\%$ Specified Lumen Maintenance = 85·0% (*see* Schedule) Lamps therefore pass this requirement.		

NOTE.—The life test is to be stopped if the average efficiency throughout life falls just below the value given in the Schedule subject to the appropriate allowance (see also Clause 18 (*c*)). To compute the value of the average efficiency throughout life for the whole of the Life Test Quantity at the end of each test period, the sum of the lumen-hours of all the lamps is divided by the sum of the watt-hours for all the lamps up to the end of that period. The following Table illustrates this for the case under discussion.

TABLE C

Computation of Average Efficiency throughout Life at end of each Test Period

Periods from start of tests	110 hrs.		197 hrs.		306 hrs.		504 hrs.		729 hrs.		1015 hrs.	
1	2	3	4	5	6	7	8	9	10	11	12	13
Lamp No.	Lumen-hours	Watt-hours	Lumen-hours	Watt-hours	Lumen-hours	Watt-hours	Lumen-hours	Watt-hours	Lumen-hours	Watt-hours	Lumen-hours	Watt-hours
1	50930	4900	90250	8760	138760	13600	etc.	etc.	etc.	etc.	etc.	etc.
2	51840	4850	etc.	etc.	etc.	etc.						
3	49010	4920										
4	51720	4800										
5	51770	4910				(and	so on)					
6	53160	4850										
7	48380	4720										
8	51520	4900										
9	49640	5000										
10	50010	4725										
Totals . .	507980	48575										
Average Efficiency throughout Life at end of period (lumens per watt).	$\frac{507980}{48575} = 10{\cdot}4$		The sum of the lumen-hours to end of each period divided by the sum of the watt-hours to the end of period must not be less than the value given in the appropriate Schedule, subject to the appropriate allowance. If it is found at the end of any test period that this condition is not fulfilled, the test is stopped at the end of that period, since the lamps have failed to pass the Specification.									

APPENDIX II

DIMENSIONS OF BAYONET CAP (ORDINARY SIZE)

1	2	3
Reference Letter	Dimensions inches	 mm. (approximate)
A Max.	0·874	22·20
A Min.	0·858	21·79
B Min.	0·590	14·99
C Approx.	0·06	1·5
D Max.	0·276	7·01
D Min.	0·236	6·00
D¹ Max.	0·315	8·00
E Max.	0·083	2·11
E Min.	0·075	1·91
F Max.	0·106	2·69
F Min.	0·090	2·29
G	0·47	11·94
H	0·22	5·6
J	0·18	4·6

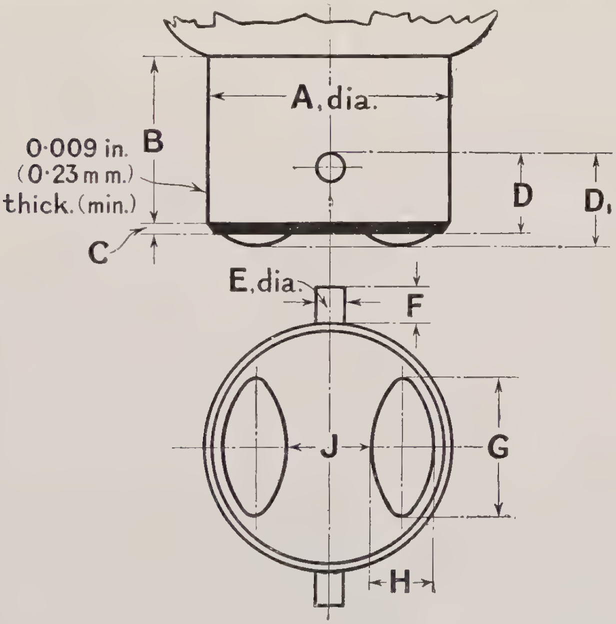

Fig. 322*a*.

APPENDIX III

DIMENSIONS OF EDISON AND GOLIATH EDISON SCREW CAP

EDISON SCREW CAP

(Not yet settled)

GOLIATH EDISON SCREW CAP

The screw thread on the Lamp Cap shall have a $\frac{1}{4}$-inch pitch, and shall have the dimensions given below.

Dimensions of Screw Thread	Maximum	Minimum
	inches	inches
Diameter at crest of thread .	1·555	1·537
Diameter at root of thread .	1·413	...
Length	...	1·024

The central contact shall have a maximum diameter of 0·709 inch, and the distance between its face and the commencement of the outer threaded portion shall be within the limits of 0·354 inch and 0·315 inch.

CHAPTER XII

THE ART AND SCIENCE OF STAGE LIGHTING

In General—Limitations of Old Methods—The New Method—First Installation in England—Modern Stage Lighting—General Lighting—The Acting Area—Footlights—Control of Light—Proscenium Lighting—The Artificial Horizon—Lighting of the Artificial Horizon—Control of Colours—The Cloud Apparatus—Panorama Projection Apparatus—Special Effects—Storms—Lightning.

THE presentation, before an audience, of a play or spectacle in which movement, the expression of emotion, and a suggestion of natural effects are three of the principal characteristics, was for centuries regarded as a matter chiefly for the actors, scenery being of the crudest description, and illumination merely a row of footlights. Modern science and the development of electrical methods of lighting have made of stage management an art which has at its disposal the most elaborate colour effects, the means of vivid and accurate mimicry of Nature in all her moods from calm to storm, and possibilities of brilliance compared with which the finest triumphs of the scene-painter become tame and dull.

Recent years have brought a greatly increased vogue for stage spectacles with exceptional scenic appeal, and the response of the public to the efforts of the producer has been immediate. The modern revue, for example, relies for its success to a very considerable extent upon gorgeous costumes, the general glow of colour, and specially designed scenery ; and in the more serious type of production, including the opera, the same tendency is apparent. The source of all this splendour, given the competence of scenic artist and costumier, rests, as it always has done, in the skill devoted to the lighting. No stage play or spectacle will give its proper effect unless it is correctly illuminated, nor will it please the spectators unless suitable illumination is available in ample measure.

Let us consider for a moment a necessity which often arises in the craft of the theatre—the representation of realistic and natural atmospheric effects.

Limitations of the Old Methods.—An outdoor scene, we may assume, would have a back-cloth showing a blue sky with clouds. However well it might be painted, it was obviously artificial; the clouds remained motionless, and the sky of canvas exhibited unpleasing folds and wrinkles which caught the dust. But there was another serious drawback. Any change, such as the approach and breaking of a thunderstorm, could not be made without the addition of complicated arrangements in order to secure the effect desired. This procedure was not only relatively clumsy, but the general result was not thoroughly convincing in its efforts to simulate such an atmospheric phenomenon. The audience was compelled to notice the artificiality of the methods employed; and the final impression tended to destroy rather than build up the illusion which is part of the charm of the theatre.

Any means, therefore, which could be devised to ensure the representation of a series of natural effects on a single background, thus eliminating changes of scenery, would prove an immense stride in the art of the theatre. And those means have been devised, as we shall describe.

The New Method.—The problem outlined in the foregoing—our chosen example being only one out of very many difficulties confronting the conscientious producer—has been seriously studied on the Continent during the last few years and has been solved successfully, a most ingenious combination of electrical and optical effects being employed, in conjunction with an apparatus termed the artificial horizon, which occupies the whole background of the stage. With this it becomes possible to reproduce within four walls almost every imaginable change in the aspect of nature. For instance, in a very short interval of time a brilliantly starlit sky may give place to a rosy dawn, the dawn growing to a bright summer day with blue sky and fleecy, sailing clouds. A transition to stormy weather is accomplished with equal ease, the sunshine gradually fading to a dull grey, and the sky meanwhile becoming overcast by masses of threatening cloud, until the whole horizon is a sullen confusion of gathering tempest.

These wonderful effects are produced on the artificial horizon, without any change in material scenery, by means of a special mechanism known as the cloud apparatus, working in conjunction with a battery of special lights called horizon lamps.

The First Installation in England.—The success of this new method of scientific stage-lighting, known as the Schwabe-Hasait system, has already been amply proved on the Continent, where it is now firmly established, and is being extensively adopted not only in new playhouses but also in existing first-class theatres.

Mr. Basil Dean, after a close study of the apparatus and its results on the Continent, realized the possibilities of the system, and arranged for its installation at the St. Martin's Theatre, London.

Modern Stage Lighting.—It is the principal aim of the engineer in charge of stage lighting to illuminate all scenery as naturally as possible, in a manner suitable to the particular performance. We have already noted the defects of the ordinary methods, whereby few changes could be made without actual scene-shifting. It is now recognized that by scientific lighting much of this labour can be avoided, and many heavy pieces of scenery formerly regarded as essentials are replaced by what we may term their 'illuminating impression'; it is sufficient to suggest the outlines of a scene—a landscape, town, or building, a realistic result being obtained simply by the aid of light, correctly projected and modified.

Modern stage lighting, with its ease of control and its endless variety of effects, only became practicable by the aid of electricity. The advent of gas marked one improvement upon the candles of Restoration days; but the first great advance was made when arc lamps took the place of gas. Obviously, here was a more brilliant source of light; but stage lighting with arc lamps presented many difficulties, and the carbon-filament lamp on account of its low candle-power was found unsuitable for the representation of full daylight. The arrival of the metal-filament lamp was welcome; but still further progress was made when, within the last few years, the gas-filled lamp was developed, and was found to be an excellent substitute for the arc lamp. It then became possible for one man to control the full range of illumination, with all its changes, from any given point. Quite recently another step forward has been taken by the manufacture of a specially shaped filament which enables these lamps to be adapted for practically all purposes.

General Lighting.—There are two principal considerations in general stage-lighting:—

(*a*) The illumination of the acting area, on which the actors move and on which the scenery is erected; and

(*b*) The illumination of the artificial horizon, and the reproduction upon it of varied natural effects.

The Acting Area.—The method employed until comparatively recently for illuminating this part of the stage consisted in the use of 'floats' or footlights (so termed because originally rows of wicks floating in oil provided the necessary light), battens, and chandeliers lowered from the ceiling. The latest methods, while still retaining the use of footlights and battens where required, rely to a great extent upon the use of specially designed floodlights, projectors, and spot-lights.

The most suitable type of floodlight contains a gas-filled lamp of 1,500 watts, with a set of reflectors specially placed to enhance the effect. The upper mirror reflects the rays which reach it from beneath, the lower one utilizes the lateral rays. Two ventilating rings are provided for cooling purposes. These projectors may be suspended above the stage, and coloured discs are employed to vary the effect. Should vertical illumination be undesirable, they may be supported in such a manner that the light is sent in any direction required.

Spot-lights are needed when certain sections of the acting area are to be sharply defined. In these the light is concentrated by means of a lens, which can be focussed telescopically and directed towards the centre of interest. By the addition of a second lens and an objective this apparatus can be used for projection purposes—that is, the throwing of a definite picture on a plane surface.

It will be seen that with these three forms of illumination a great range of effects is at the disposal of the producer. The function of the floodlight is to illuminate a comparatively wide area—open-air scenes, pageants, or other displays where quantity of light is important rather than quality. The spotlight is employed when a small area has to be intensely illuminated, leaving the surrounding portions by contrast unaffected. The projection apparatus gives special effects; the diameter of the lighted zone can be accurately regulated, and an illuminated picture can be formed and varied by using shutters of different shapes having circular, elliptical, or rectangular apertures. With this it is possible to throw light on a head, a costume, or any particular object without illuminating the surrounding region; and by the use of painted slides instead of shutters, any number of different impressions may be created, such as sunlight through foliage, sunlight shining through a church window, and other fascinating representations.

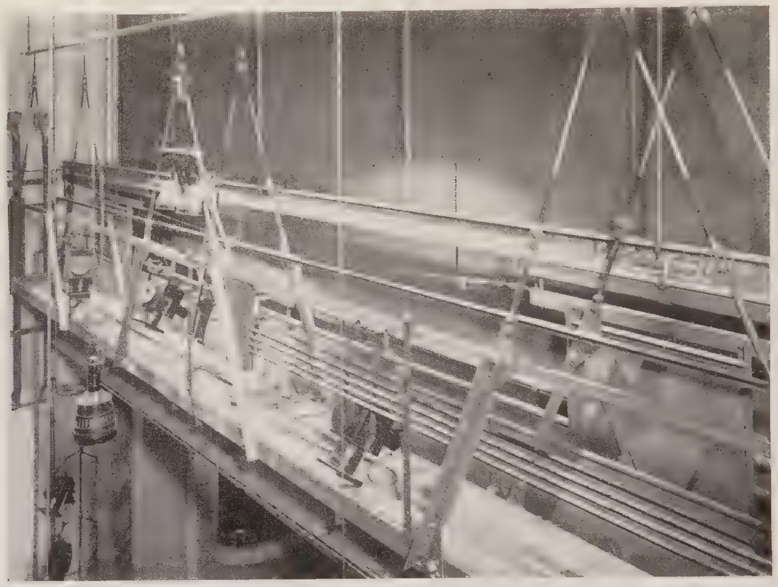

Fig. 323.—Acting Area Floods and Lightning Apparatus.

Footlights.—At various times the use of footlights has been condemned; they are necessary, however, to the modern theatre, because lighting from below is generally regarded as essential. As with other modes of illumination, the footlights have been greatly improved, and those in use to-day are considerably in advance of the older types. ‘The glare of the footlights’ has become a familiar phrase; but it no longer applies. Indirect lighting has recently been adopted; the actors are protected from the dazzling effect by so placing the footlights that they are almost hidden in the stage floor. Tubular lamps are used, fitted with suitable mirrors and reflectors which throw the light upward.

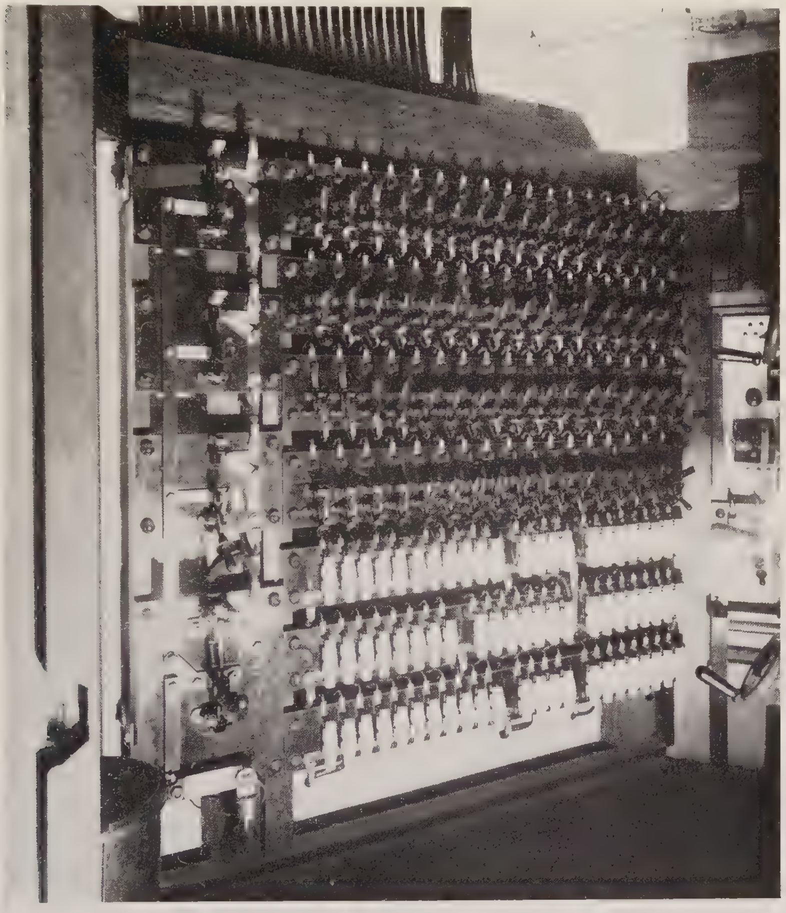

Fig. 324.—Switchboard in Control Room.

Colour effects are an important feature in theatre-craft, and in this direction also many improvements have been made. The dipped lamp was unsatisfactory on account of the short life of the colouring layer, and another method is to use special lamps which are impregnated with colouring matter during manufacture, with the result that a permanent colour is obtained. As an alternative, uniformly tinted glasses, called colour filters, may be placed in front of the lamps. The footlights are arranged in sections with suitable electrical control, so that all or any sections may be switched on at will.

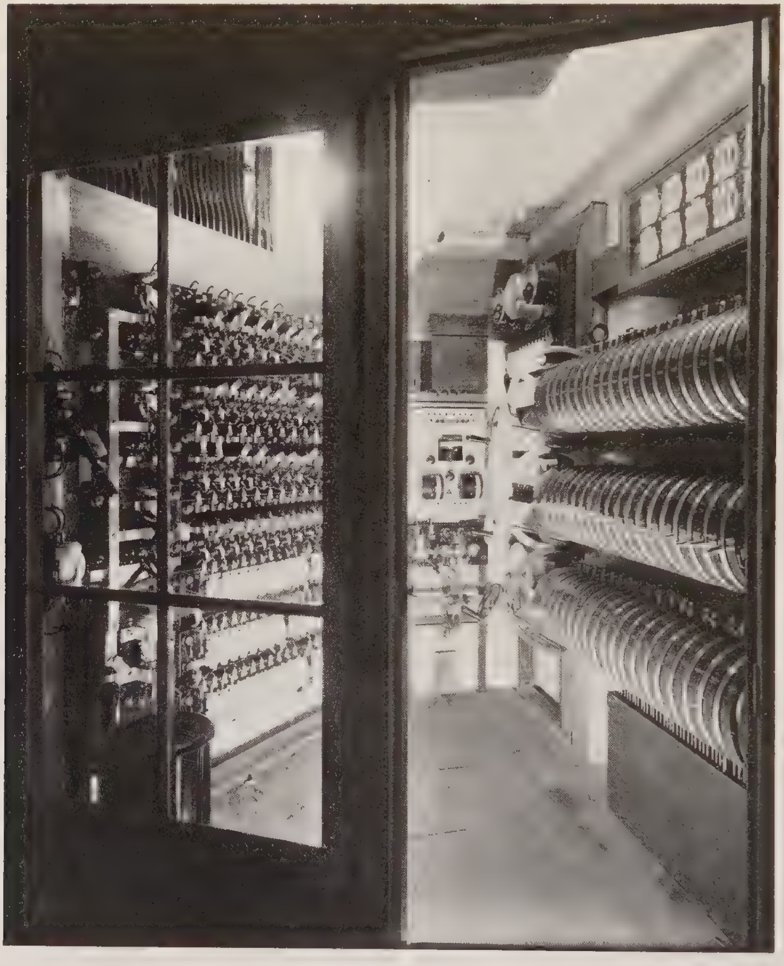

FIG. 325.—MASTER CONTROLLER AND SWITCHBOARD.

Control of Light.—It is very necessary that the illumination of the stage should be instantly and easily controlled, so that all possible gradations of light may be attained. The cold grey light of dawn is often desired, or the warm red glow of sunset. Some scenes may demand sudden variations in strength of lighting, or slow, almost imperceptible changes from the softest to the most brilliant effects. Partial lighting, transitions of colour—all must be capable of production at will. To deal successfully with this problem, a regulating apparatus is necessary which will enable the illuminating engineer to control his light-waves in much the same way as an organist controls his sound-waves. In fact, the modern stage-lighting control may very fairly be compared to the control of an organ, its function being to regulate the quantity and intensity of light, just as the volume and quality of sound in an organ are modified by keyboard, stops, and pedals.

The various types of illuminating apparatus which have been described, and others even more striking which we shall mention later. all require careful handling. By ingenious electrical and mechanical devices it is possible to centralize all control so that the complete range of effects is at the command of a single operator. At the same time, each lighting unit, having its own electric circuit, can be operated independently when necessary, so that a very complete and precise regulation is obtainable.

The regulator which secures the desired changes, from darkness to fullest brilliance, may be termed the brain of the lighting installation. It is a purely mechanical device, consisting essentially of a series of levers arranged in rows placed one above the other and connected by steel wires running over pulleys to a number of movable contacts sliding over resistance steps.

By operating the levers, resistance may be either inserted into or cut out of the various lighting circuits, thus dimming or raising the lights as required.

Each lever is arranged to move over a scale, divided into a number of parts, the scale divisions corresponding to definite positions of the resistance contact controlled by the lever. Regulation can therefore be made extremely accurate, and definite variations in the intensity of light may be repeated as often as desired.

The effects required having been worked out experimentally at rehearsals, the operator is able to note the positions of his controls ; he therefore has only to reset them at the points recorded in order to obtain the known results.

It is occasionally necessary that a number of levers should act in unison ; for example, if an actor carrying a lamp appears, the whole stage may have to be suddenly illuminated. A device for this purpose enables each lever to be mechanically coupled to a spindle capable of operating all the levers in a tier simultaneously.

The change from daylight to dusk, or from night to daylight, necessitates the simultaneous alteration of the resistances in several circuits—an operation which must be carried out slowly. For this purpose the levers are again coupled to the shaft, which in this case is controlled by a special slow-motion gear which allows the required changes in the intensity of the light to be effected without the slightest difficulty.

A full description of this regulator is somewhat technical, and it is therefore not proposed to enlarge on its details in this work.

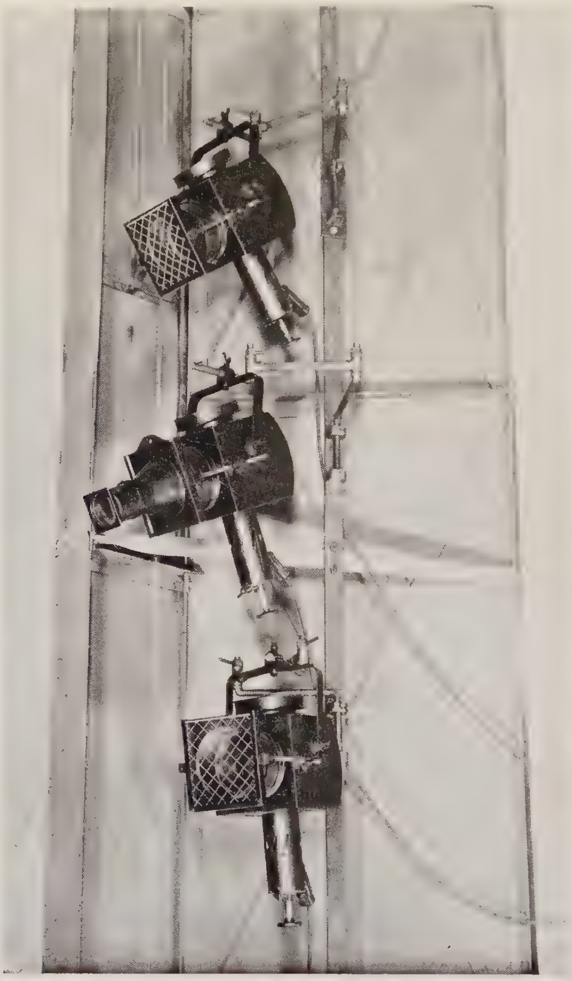

Fig. 326.—Proscenium Units, showing Method of Fitting.

It should be pointed out, however, that the design is such that an intelligent operator should not experience any difficulty whatever in operating it under working conditions. In order to obtain the best results it is advisable that the regulator should be so situated that the operator can command a view of the whole stage.

The resistance-chamber should be a separate room or compartment, in reasonable proximity to the stage, and should be properly ventilated in order that the heat given off, when the resistances are in operation, may be carried away.

Proscenium Lighting.—Until within the last few years the footlights formed a barrier between actors and audience, not to be crossed; stage and auditorium were two distinct and entirely separate parts of the theatre. Recently, however, the vogue of the 'revue' and similar theatrical productions has brought the actors from the principal stage into the part hitherto reserved for the public, certain effective situations otherwise unattainable being thus rendered possible.

Fresh problems in lighting arise from this popular change, as the lights of the acting area can no longer be used, the proscenium wall not being available. The footlights are, of course, useless; vertical lighting and side lighting are impracticable.

Various attempts were made to use floodlights or spotlights to illuminate this forward area, and it was finally found that the only quarter where lighting apparatus could be employed satisfactorily without interfering with the vision of the audience was the ceiling of the auditorium. If the rays fall almost vertically from there, they are hardly noticeable; the effect is all the more striking since it achieves the ideal of the illuminating engineer—that light should be visible only when it falls upon the required spot.

The Artificial Horizon.—We now come to one of the most notable advances in stage-craft made in recent years—a step forward as revolutionary in its results upon scenic effects as was the change from old-fashioned footlights to electric lamps. No conception of the astonishing qualities of light itself entered into the preparations of the scene-builder of former days; his endeavours at reproducing the wonderful phenomena of nature were accepted by the public only because they knew of nothing better.

In modern stage lighting the canvas gives place to an arrangement known as the artificial horizon, visible only as a reflector of light, unobtrusive, and producing an extraordinary illusion of depth and atmosphere. It may have the shape of a cupola or of the surface of a cylinder, and is brilliant white, in order that all rays falling upon it shall be reflected equally, with the smallest possible amount of absorption. From any point of the auditorium the effect is wonderfully good, the sense of depth and distance which it is the object of all landscape backgrounds to produce being enhanced to a remarkable degree.

Apart from the results obtained from a spectacular point of view, which we shall describe in detail, there is a great deal to be said in favour of the artificial horizon from the standpoint of economy. It is possible, for example, to do away with a large proportion of the flats and side scenery—and therefore, of course, with a corresponding amount of labour in scene-shifting. A few stage 'props' standing out sharply defined against the horizon can be substituted for the customary pieces, which occupy so much space and necessitate continual alterations in setting.

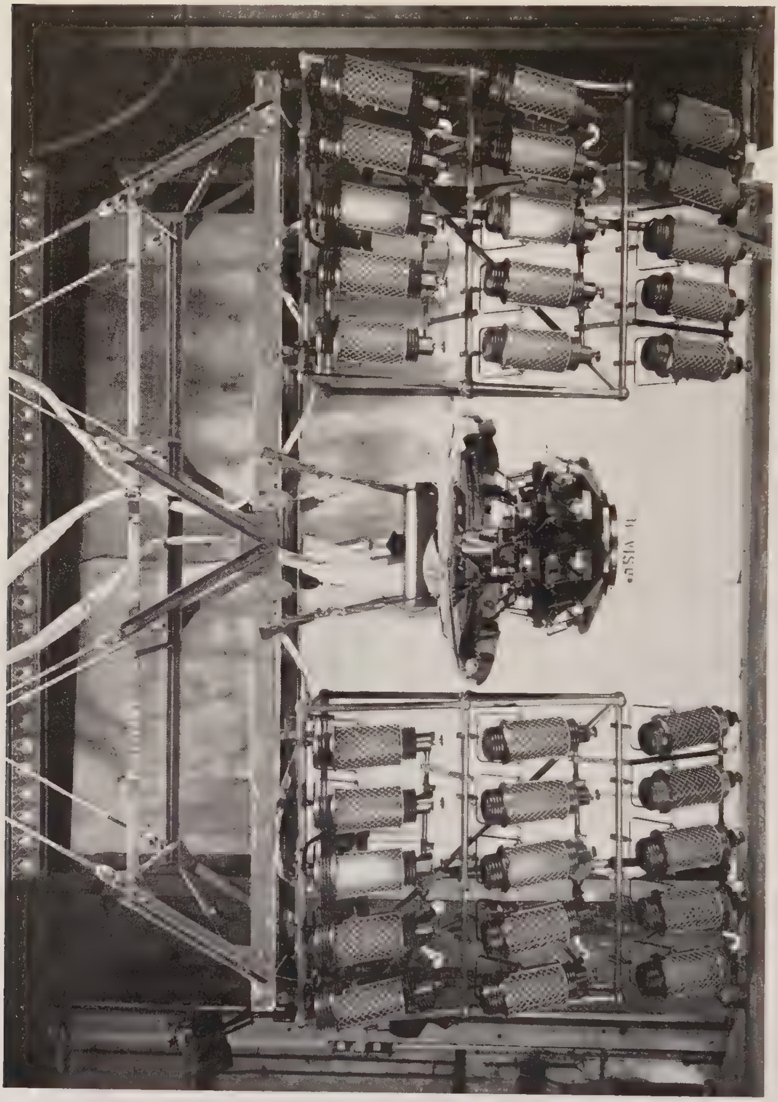

Fig. 327.—Horizon Floods and Cloud Apparatus.

The artificial horizon can be erected as a permanent structure by covering a suitable framework with a layer of polished plaster of Paris; this method, however, has certain disadvantages in its unavoidable obstruction of the general movement, and the liability to damage of the polished surface. These drawbacks have been overcome by the invention of a movable artificial sky, consisting of large sheets of canvas sewn together and perfectly stretched in a manner that leaves not the slightest fold or crease visible. The smooth screen thus formed runs on a semicircular rail fixed across the back of the stage, and is operated by an electric motor which rolls or unrolls it in a few seconds. Thus for the setting of a scene representing an interior it can be quickly rolled up out of the way.

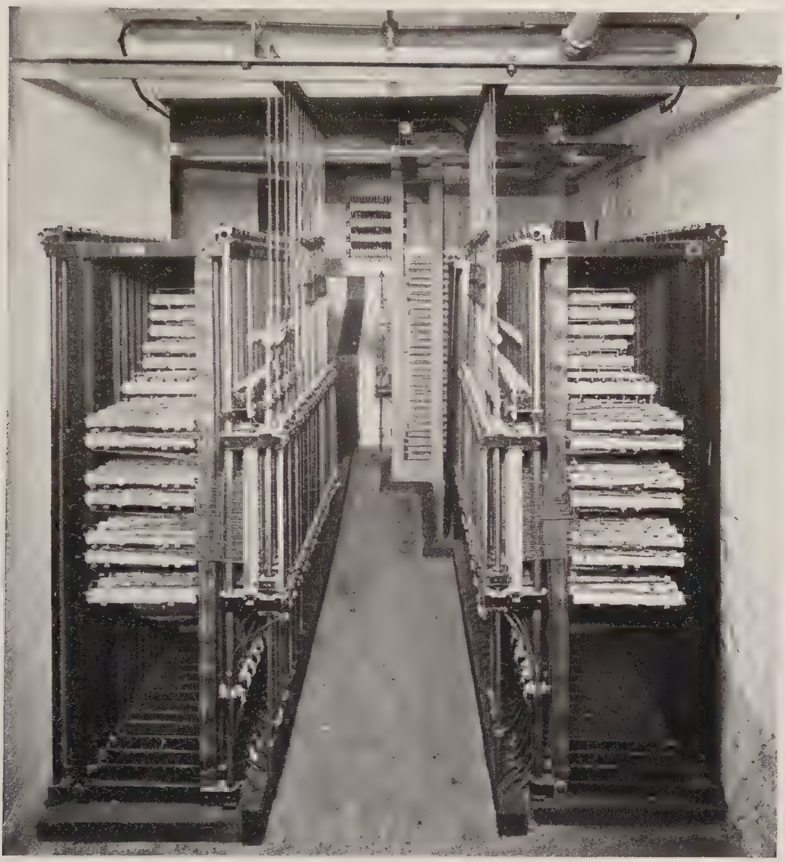

Fig. 328.—Two Resistance Units, showing Arrangement of Tracker Wires to Master Controller.

The Lighting of the Artificial Horizon.—For the correct illumination of the artificial horizon very strong light, variable at will both in colour and in intensity, is required, and the ideal source is the gas-filled lamp, without which, indeed, many of the marvellous effects produced could not be obtained. A number of high-candle-power lamps contained in special housings are used, the number depending upon the size of the horizon, which in turn is governed by the dimensions of the stage itself. These are shown in the illustration on page 368.

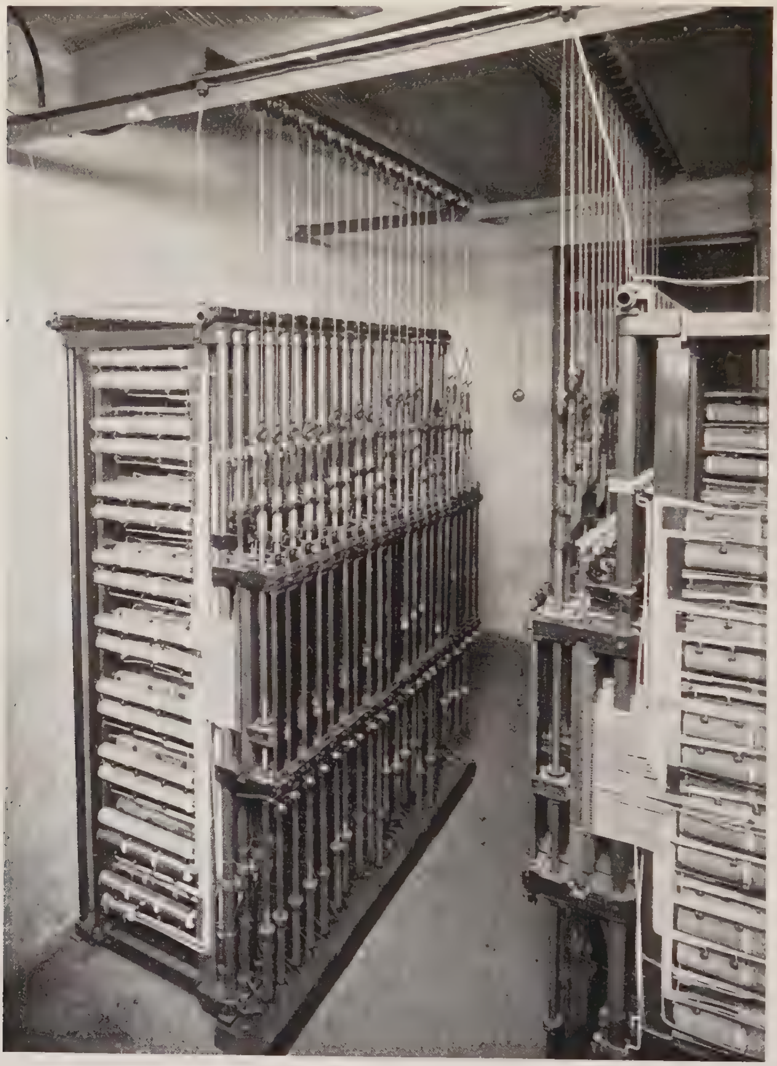

Fig. 329.—A Dimmer Unit, showing Arrangement of Rheostated Control.

The horizon lanterns, each containing a 1,000-watt tubular-type gas-filled lamp fitted with an aluminium reflector and a coloured glass slide, are built up in three or four tiers, forming a homogeneous unit, and are supported in a rigid metal framework suspended from the roof.

The representation of natural effects—such as dawn, sunrise, the blue sky of broad day, sunset, twilight, etc.—is possible, with innumerable shades and intermediate gradations, by the use of the artificial horizon, and the scientific combinations of colour necessary for these charming sky-pictures have been studied exhaustively and worked out to a nicety. It is a well-known fact that the atmosphere absorbs the rays of the sun to a varying extent according to the angle at which those rays pass through it to the observer. At sunrise and sunset, for example, the red rays are transmitted more freely, the light striking almost horizontally through thicker layers of air. At noon we find the blue rays transmitted; and at various times and seasons atmospheric changes will cause different and often very beautiful modifications of light and shade and colour. The reproduction of this range of natural effects within the four walls of a theatre may be regarded as one of the triumphs of modern stage lighting.

A natural shade of blue is given by the rays emitted from high-wattage lamps, used to illuminate the upper horizon; and as each lamp has its intensity of illumination under perfect control, any variation in the depth or paleness of the blue sky can be obtained. The dimming of the lamps by the switching in of more resistance causes a red glow; this could also be produced with the old type of carbon-filament lamp, but the blue tints were beyond its capabilities. To obtain the various colour combinations required in the representation of sky effects, each horizon lamp is fitted with a colour slide, the colours used covering the whole range which has been found necessary in practice. By a suitable combination of various colours it will be seen that a very wide series of tones is available by which any natural sky phenomena may be produced. A dark blue group of lamps at full power, for instance, gives the spectator the impression of a summer noonday; the same group when dimmed throws the deep velvety blue of a fine night sky on the artificial horizon. With the dark blue and green combined and dimmed, the appearance of moonlight is obtained. A mixture of certain groups gives an evening sky before sunset. The clear, rain-washed sky of spring days is produced by the paler green and blue groups. But there is no need to describe the complete range of effects; the grey sky of stormy weather, the low red tones of dusk, the glare of noon, or the pure primrose dawn, and all the slow merging of one effect into another so continually observed in nature, can be imitated with astonishing accuracy in a way that has never before been possible.

Control of Colours, etc.—Complete and flexible control of the lighting of the artificial horizon is obtained by a master control apparatus which operates a series of resistances in circuit with the individual lamps. This is designed in such a way that dimming or raising the light takes place smoothly and easily, with none of the objectionable jerky effect which often spoils an otherwise pleasing scene.

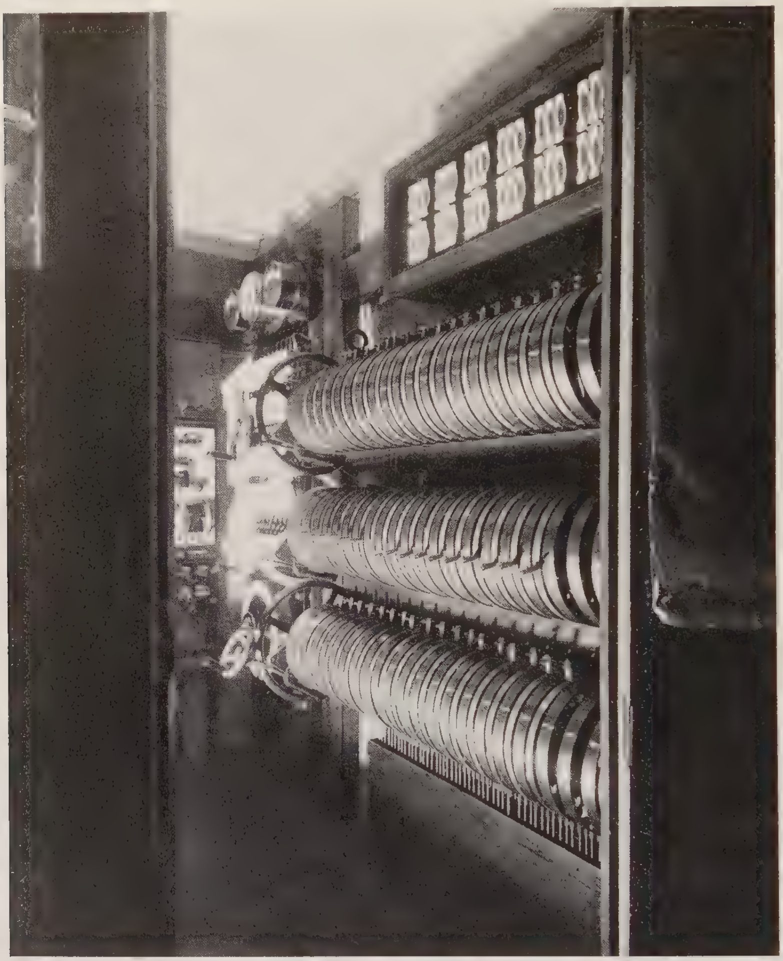

Fig. 330.—The 'Brains' of the System—the Master Controller.

As the source of light is at a high level in order that it should not be perceptible to the audience, it follows that the lower part of the horizon does not receive from it the same intensity of illumination as the upper portion. To remedy this a certain number of lamps placed at the level of the stage, of the same power and type as those already described, are employed. These are contained in movable trolleys, spaced round the bottom of the screen, and are supplied with colour slides and arranged so that they can be tilted at any angle.

As the amount of heat generated by the installation is considerable, ample provision is made for the adequate ventilation of the lamps; and in addition each lamp is protected by wire guards from accidental breakage.

The Cloud Apparatus.—So far, we have been dealing with the reproduction of clear-sky effects and colour changes; but a far wider range even than these is possible by the use of the cloud apparatus in conjunction with the artificial horizon. Half the beauty of the sky consists in the movement and shape of its clouds, and the old method of painted canvas scenery gave no opportunity for simulating this beauty in the theatre. Nor was it free from absurdities, such as the painted clouds which remained stationary in the howling storm, or the cloud which gave no sign of motion during a whole scene—makeshifts which, as we noted, were accepted as legitimate only for lack of something better.

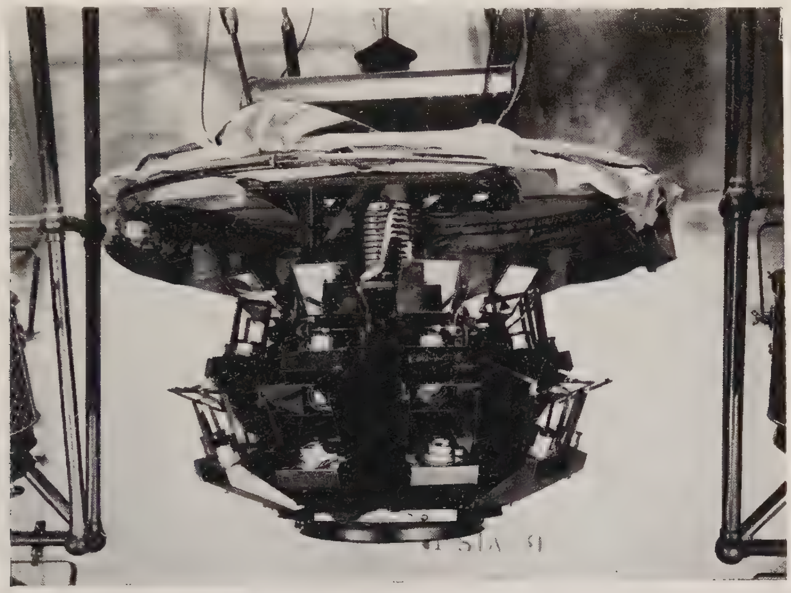
FIG. 331.—CLOUD APPARATUS.

The artificial horizon, with its wonderful command of light and colour, offered an ideal setting for the reproduction of moving clouds; and the cloud apparatus, as its name implies, is a mechanism by which a series of cloud-pictures can be projected upon it.

The apparatus consists of two essential portions: one, which is stationary, carries the main driving motor, the collector rings, and a 3,000-watt gas-filled lamp; the other, which rotates round the first, carries the system of cloud-pictures, lenses, and reflectors, also two small motors which drive two lines of shafting by means of suitable gears. These shafts give motion to a series of eccentrics which cause a number of reflectors to rotate through a definite angle, thus causing the cloud-images to rise or fall as desired.

The moving system has its cloud slides arranged in two tiers. Immediately behind each slide a condenser transmits the rays from the lamp through the slide on to a fixed glass reflector; this in turn transmits the picture through an objective lens on to a movable glass reflector actuated by one of the eccentrics, and this reflector throws the picture on the horizon screen.

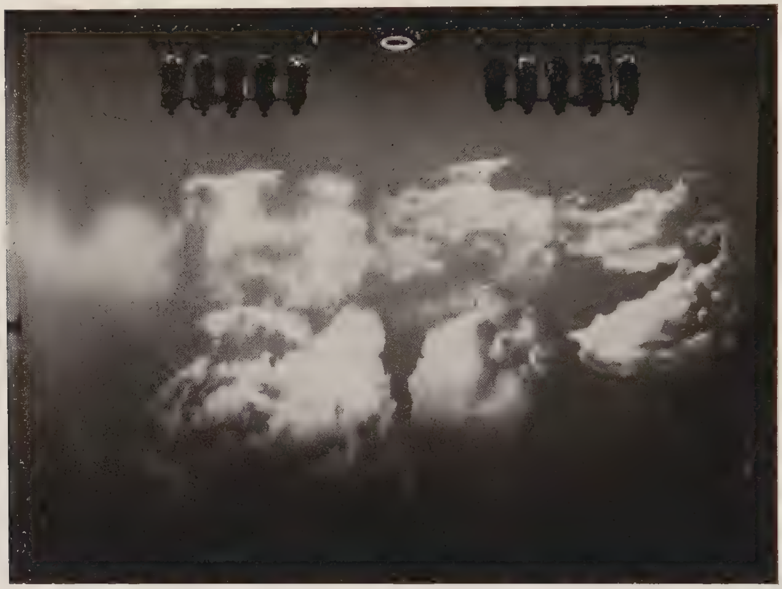

Fig. 332.—A Moving Cloud Picture, showing Horizon Floods and Bottom of Cloud Apparatus in position. These, of course, cannot be seen by persons in the auditorium.

The slow motion of clouds across the sky is simulated by the rotation of the two tiers, which are driven by the main motor through reducing gears; this motor is reversible, so that the clouds can move from right to left or *vice versa*, and by combining the horizontal with the vertical movements diagonally travelling and thickening clouds may be produced. One particularly interesting effect obtainable by the combination of these movements is that of two separate banks of cloud travelling independently one above the other, a phenomenon frequently observed in nature. The rate of movement is variable through a range of speeds, the motors being equipped with speed-regulating devices.

Different effects are caused by dimming the light, the clouds appearing dense and heavy or white and fleecy; and by varying the voltage many impressive results can be secured. By lowering it gradually, for instance, a cloud may be made to appear slowly forming in a clear blue sky, growing and spreading until the whole heavens are obscured by heavy masses of cumulus indicating the approach of a storm. And as in all these effects the clouds are reproduced from actual photographs, they are absolutely true to nature.

Fig. 333.—A Typical Cloud Picture.

The success of the cloud apparatus is greatly influenced by the manipulation of the horizon lighting, which creates the illusion of the sky itself.

We can do no more than allude, in this necessarily brief description, to the years of research which have led up to such a remarkable triumph of stage-craft and brought it to its present state of perfection and reliability. Nor can our description give an adequate idea of the exquisite results obtained, which, in the hands of a skilful operator, reproduce at will practically any atmospheric phenomena of nature. They must be seen to be believed.

Panorama Projection Apparatus.—The effect of the cloud apparatus may be intensified by the addition of the panorama projection apparatus, which projects a series of cloud-pictures or landscapes on the artificial horizon.

It may be used independently also, with excellent results. It consists essentially of three projectors mounted on a tubular steel frame, capable of being tilted in an upward or downward direction, and with each lamp mounted in such a manner that it can swing on its horizontal axis and be locked in the desired position by a set screw.

The raising and lowering movement is obtained by a small motor driving a screwed spindle, the rotation of which operates wires attached to the projectors.

Each projector, in addition to its 3,000-watt gas-filled lamp, adjustable by means of a hand wheel operated from the exterior, is equipped with an adjustable reflector which enables the focus of the beam of light to be readily corrected.

Two discs are fitted to each lamp, one being a colour screen, the other containing several dia-positives, so that it is possible (to take one illustration) to obtain three entirely different panoramas without the necessity of changing slides. In front of the projector lens a circular motor-driven colour screen is fitted, by which the operator can control various special colour effects.

With this apparatus the only limits may be said to be set by the imagination of the producer. When used for cloud effects in co-operation with the cloud apparatus, the most marvellous cloud-scapes are formed with the greatest ease, the operator then having at his command two different sets of cloud-pictures, a moving and a fixed series, with which he can produce almost any conceivable combination on the artificial horizon.

Special Effects.—*Storms, Lightning, etc.*—In modern stage lighting provision is made for many special and spectacular effects which may add to the popularity of the play or piece, in practically all of which electricity is employed. The imitation of a storm, to take one example, was always, and probably always will be, a favourite sensation ; but we have progressed greatly since the barn-storming days when a violently shaken sheet of tin was considered a good imitation of thunder. The crash of thunder is now finely imitated by a clever mechanical device, part of which consists of a drum rotated by an electric motor, the intensity of the sound being electrically controlled.

Lightning, on the modern stage, may be termed ‘ real ’ rather than imitation, since it is produced by an electrical discharge. Special arc lamps with impregnated flame-carbons are used. As soon as the current is switched on, an arc is struck, only to be broken immediately by the rapid raising of the upper carbon by means of a coil ; the sudden flash is projected through a shutter having a suitable aperture, thus giving a vivid momentary glare. The carbon is retained in its raised position until the switch is opened. Several discharges in succession may be obtained if necessary, and the shutter is made to rotate, its various openings producing a different type of flash.

Wind and storm are simulated, apart from visual phenomena, by another ingenious device. An electric motor operates a series of radial rods of cane or steel, which when rapidly rotated produce a whistling sound, the loudness of the effect varying with the speed.

Even a rainbow can be thrown on the artificial horizon. The light from a projection lamp is split into its component colours, giving a result similar to that obtained when the sun's rays pass through the drops of a shower and fall upon a cloud. A shutter with an opening shaped to a small arc is placed in front of the condenser, and the rainbow appears in its familiar prismatic hues. It can be caused to appear and fade gradually.

Sun, Moon, and Stars.—As a general rule, the sun and the moon are not reproduced in theatrical art, their light effects only being shown by reflection on the artificial horizon.

If, however, it is considered necessary that they should be seen, special arrangements are needed, the character of which depends on the problem to be solved.

Stars are shown, if the plaster screen is used, by small lamps placed behind tiny perforations, the lamps being controlled from the switchboard. When the movable canvas artificial horizon is used, other special methods are required.

We have endeavoured, in this explanation of the Schwabe-Hasait apparatus, to give the reader a general idea of the scope and possibilities offered by the new lighting methods which are now available; and, in concluding this necessarily somewhat brief survey of the new field opened up to the producer as a result of the patient experimental work of recent years, culminating in the successful evolution of this system, we would draw attention to the following advantages claimed for it:—

Firstly.—It is possible to do away with a considerable number of ‘ drop ’ scenes, as the artificial horizon itself forms the only background now required for the presentation of sky effects of every description; and as each new play necessitates a fresh supply of scenery, it is obvious that a considerable economy should result in this respect.

Secondly.—It should be noted that the tremendous range of effects obtainable upon the screen is under the control of a single operator, who, in addition, works all the subsidiary lighting, such as battens, floats, projectors, flood- and spot-lights. This centralization of the complete operating system in the hands of one man not only conduces to efficiency, but should also result in an economy in personnel.

Thirdly.—It may be pointed out that this system is not limited to the presentation of purely realistic effects, but may be used to produce futuristic or impressionistic results by calling in the aid of the scenic artist to design suitable slides. It will therefore be seen that, while satisfying the ideal of perfect realism, it may also be used for the representation of the most fantastic ideas of the modern producer.

It may be thought that the system is only suitable for use in purely outdoor scenes, but a little consideration will show that it can also be employed for brilliantly illuminating landscapes, etc., seen through windows and doorways in ordinary ' chamber ' plays.

Finally, the artificial and somewhat crude attempts at nature effects which we have seen in the past are completely eliminated; a new field is opened up to the producer, who now has at his command resources enabling him to represent within the four walls of the theatre the whole majestic range of atmospheric phenomena to be observed in nature.

The whole of the photographs in this section were taken at the Fortune Theatre. They have not been retouched in any way, the object being to expose, as far as possible, the exact location of units and methods of fixing them.

CHAPTER XIII

ELECTRIC SIGNS AND TRAIN LIGHTING

Evolution of the Electric Sign—Piccadilly Circus—'Speller' Flasher—Combination Flasher—Brush for Flasher—'Speller'-Type Sign—'Script'-Type Sign—Sky-Rocket—Ascending Smoke—Kaleidoscopic Effects—Sunrise Effects—Chasers and Running Borders—Train Lighting Designs—Typical Units—Lamp Curves.

WITH the advent of electricity for lighting purposes it was quickly realized that the new illuminant could be utilized as an excellent advertising medium ; the result was that electric signs of the stationary nature commenced to appear in our main thoroughfares. This type of sign was quite satisfactory provided it was erected in a position where it would be outstanding from its surroundings. After a very short time, however, numerous signs of this nature were erected in the front of, and at various angles from, buildings which were situated close together, with the result that they lost their attractive power because there was not sufficient contrast between them to 'strike the eye.'

From this we do not wish to convey the impression that this type of sign is ineffective ; it is excellent provided it can be fixed in positions where attention is not distracted from it.

The animated sign combined with colour-sprayed lamps is undoubtedly the most attractive medium at night-time that has yet been produced ; movement immediately attracts the attention, and a choice of colour at once makes the sign distinctive irrespective of its surroundings. This is at once apparent if one visits the sign centre of England—Piccadilly Circus ; we reproduce one photograph of Piccadilly Circus taken at night-time (Fig. 334). Practically the whole of the signs are of the animated type, and, although portrayed here in cold black-and-white, it can be seen that each sign strikes a distinct note in its attractiveness.

It is hardly necessary to deal with the evolution of the animated electric sign. It may be mentioned, however, that the first sign of the animated type was the invention of an American, Major W. J. Hammer, but it was shown for the first time in England by him in 1882 at the International Exhibition at the Crystal Palace ; its position was over the great organ, and the message it had to convey consisted of the one word—EDISON. The sign was operated by hand by means of a commutator switch, the effect being to illuminate each letter one after the other until the whole word appeared. The word was then switched off and the cycle of operations was repeated.

The same sign was shown by Major Hammer in 1883 at the Berlin Health Exhibition; the message was the same—Edison. A large number of improvements had been carried out, however, so that the later sign was distinctly better than the previous one. The outstanding improvement was, perhaps, in the operation of the sign. Whereas in the first case a hand-operated commutator produced a letter-by-letter switching effect, the second sign was operated by a motor-driven flasher. It is certainly a high tribute to Major Hammer's ability that the care and thought he embodied in the design of his flasher formed the basic principles upon which modern flashers are designed.

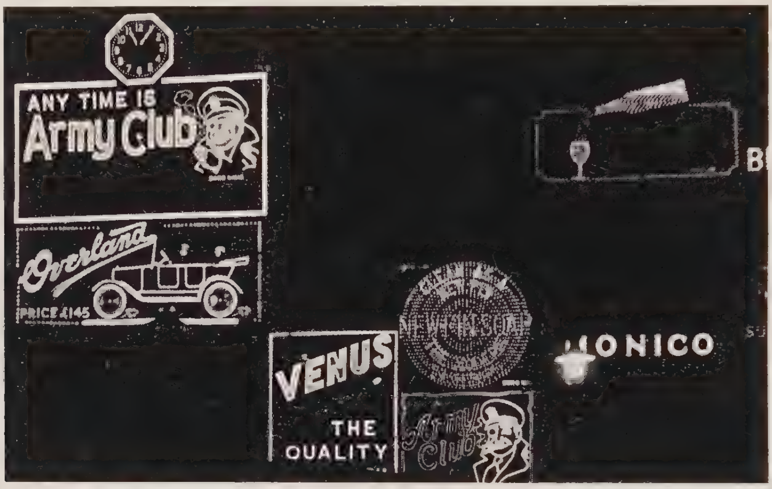

Fig. 334.—A few of the Signs in Piccadilly Circus, London.

Compared with the sign of to-day the earliest animated signs must be considered very crude affairs; the introduction of the metal-filament lamp has made possible animated effects in signs which would have been absolutely impossible with the old carbon-filament lamp.

One of the characteristics of the carbon-filament lamp was that a certain amount of time was occupied after switching on before the filament reached its maximum temperature. Similarly, after switching off, a certain amount of time elapsed before the lamp was quite dark. This necessitated very slow operation, a fatal feature in present-day signs.

The illusion of running borders, or 'chasers' as they are sometimes termed, depends upon electric lamps being rapidly illuminated and extinguished one after the other. These rapid fluctuations over a certain distance of the border cause the eye to be deceived and the impression of movement is conveyed to the brain. The filaments of modern lamps reach their maximum temperature almost immediately they are switched on, and when switched off their temperature is reduced with equal rapidity. This makes them eminently suitable for operation in electric signs. Until recently colour effects were obtained by dipping lamps in various-coloured varnishes ; the method was not very satisfactory because of the inability of varnishes to withstand heat and weather conditions. The introduction of colour-sprayed lamps solved the problem to a certain extent, since the material with which the lamps are sprayed is practically impervious to heat, and tests have proved that it will withstand intense cold, rain, snow, and sea-water ; the penetrating power of colour-sprayed lamps is, however, very low.

For distance signs the difficulty is completely overcome by covering clear lamps with hoods of natural-coloured glass; this arrangement produces colour light having the same penetrating power as clear light. The initial cost of this method is greater, but with care colour hoods will last many years, so that, in time, they will repay the cost expended upon them in the first instance, because the clear lamps can be replaced at any time without any additional cost for colour.

The apparatus necessary for an animated sign is :

1. A fractional horse-power motor.
2. A flasher.
3. A number of lamps in the form of an attractive design.

The motor drives the flasher to which the lamps, divided into circuits, are connected ; each contact ring on the flasher controls a certain number of lamps, and the position of the rings is such as to provide the necessary contact sequence.

There are four distinct types of motor-driven flashers : (1) speller, (2) speed, (3) script, (4) crawling ; through the use of one or more of these types in combination any desired effect can be obtained. The purpose for which these units are used is as follows :—

Speller.—These are used for spelling out signs letter by letter, or word by word ; they are suitable for building words up or down, plain on-or-off flashing, colour changing, or for master control of complicated effects.

Speed.—This type of flasher is for operating mostly spectacular signs, such as lighting, waving flags, flames, revolving wheels or globes.

Script.—As the name implies, this type of flasher is suitable to produce the effect of handwriting in script letters. Rockets, streamers, etc., can also be operated.

Crawling.—All travelling borders and revolving circles, etc., are operated by this type of flasher.

Sign flashers have, probably, to withstand the most severe service demanded of any switchgear. For example, the fingers on a 'speed '-type flasher may have to make and break their respective circuits more than 600,000 times per week during the winter months; it follows, therefore, that sound mechanical and electrical design is of vital importance, and it is only machines which are constructed of the best materials that can stand up to such arduous conditions of service.

In Fig. 335 is illustrated a 'speller'-type flasher; the gears are cast-iron, steel worms and pinions ensuring positive drive and accurate timing.

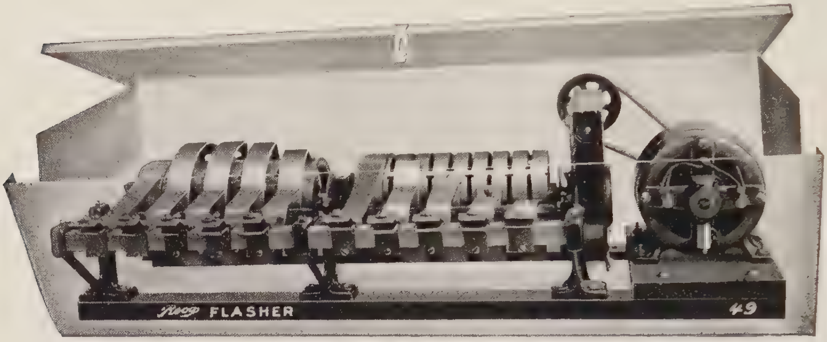

Fig. 335.—A 'Speller'-Type Flasher.

A combination flasher is illustrated in Fig. 336; this is a combination of two or more types, used for spectacular displays, in order to produce the proper electrical effect. In Fig. 337 is illustrated the construction of the type of brush used with these flashers. It is built up with copper leaves, and has a phosphor-bronze spring back, and is reinforced at the contact-making point; it can be reset without disturbing the connections.

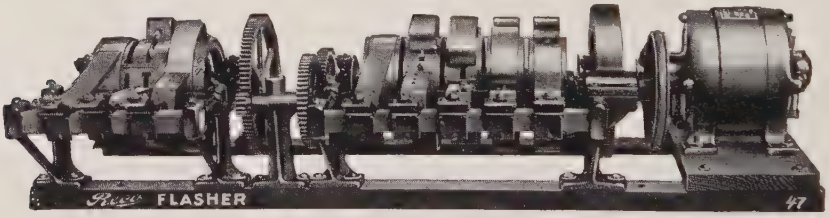

Fig. 336.—A Combination Flasher.

The contacts are fastened by means of bolts and nuts, which slide in the drum-slot, making resetting a simple matter. Often, after a sign is connected, a change is desired; the construction illustrated in Fig. 338 enables changes or adjustments to be easily made, a screwdriver being the only tool required.

Regarding the circuits between flasher and lamps, it may be said that the 'speller'-type sign is the most simple; a complete diagram of connections of this sign is illustrated in Fig. 339. From this illustration it will be seen that a common return is looped in from the flasher to the motor side of the double-pole switch. The circuits numbered 1, 2, 3, 4, 5 are connected between the flasher and the whole of the lamps in the respective letters; the lamps in each letter are connected in parallel, one side being connected to the flasher, a common return between the lamps in the whole of the letters and the dead side of the double-pole switch completing the circuits. This sign, when in operation, compels attention until the whole of the message is delivered.

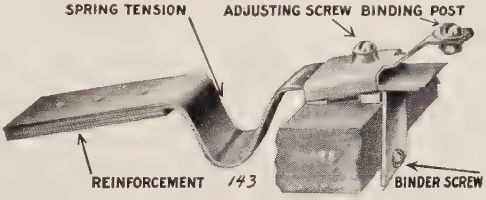

Fig. 337.—Typical Brush for a Flasher.

The circuit diagram of the 'script'-type sign, illustrated on the same page (Fig. 340), is much more complicated than the one previously explained. Script letters are usually wired two lamps to a circuit; then, if the total number of lamps is 100, 50 circuits and 50 brushes on the flasher are required. A flourish or tail is usually flashed in as one. In letters of large size, 4, 6, or 8 lamps per circuit can be used without impairing the effect. All lamps composing the script letters are connected to the flasher in a 1, 2, 3, etc., sequence imitating the writing motion.

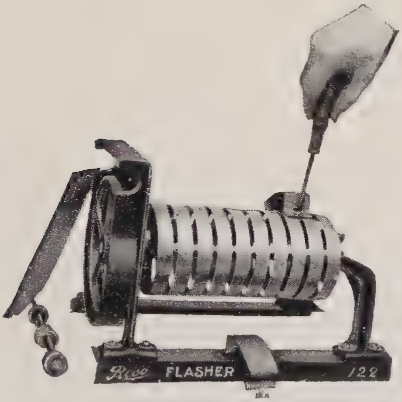

Fig. 338.—Simple Construction permits Ease of Adjustment.

Fireworks, rockets, Roman candles, and other imitations of pyrotechnic displays are very attractive. People like to look at spectacular displays; they talk about them, and this is assuredly a most effective form of advertising.

In Fig. 341 is illustrated a complete circuit diagram for a skyrocket. The first circuit at the base of the rocket consists of six lamps, the next five, etc., and at the curve single lamps. This arrangement shows acceleration at the start and slowing-up as the 'burst' is reached. The burst is wired in two or three circuits and the streamers in double rows as shown.

The circuit diagram gives a comprehensive idea of the operation of this type of sign; different designs and a greater number of lamps require certain modifications.

A very attractive illuminated sign is one which creates the illusion of ascending smoke; this sign is illustrated in Fig. 342. The wiring in this case is in crescent form, the shapes, size, and lengths being irregular; the semicircles are connected to 1, 2, 3, and 4 in an upward and outward direction.

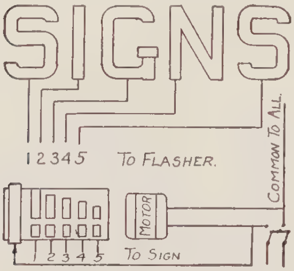

Fig. 339.—A 'Speller'-Type Sign.

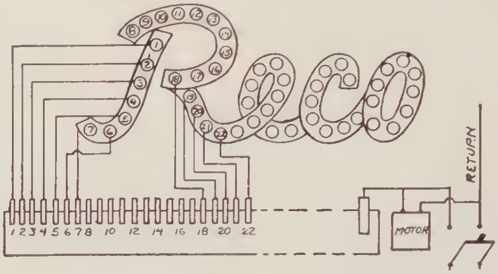

Fig. 340.—A 'Script'-Type Sign.

A 'speed' flasher is used for this sign if the energy consumption of the circuits does not exceed 400 watts. Above this consumption it will be necessary to run another set of circuits, when, of course, a combination flasher would be used.

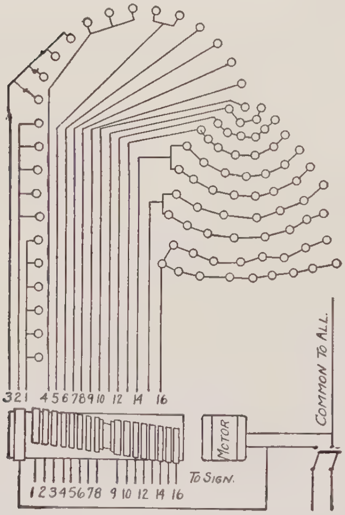

Fig. 341.—A Sky-Rocket.

Rays, sunrise, and similar effects are wired in semicircular rows. For rays, the wiring follows the 1, 2, 3, and 4 principle with a four-brush 'speed' flasher. Sunrise effects should be wired in eight circuits with an eight-brush 'speller'-type flasher (this is provided if there are eight semicircular rows in the design). The flasher will require more or less brushes according to the number of circuits in the design.

The wiring diagram for sunrise effects is shown in Fig. 343. At the bottom of this illustration an arrangement is indicated by which the circuits are controlled when the sign is operated on a three-wire system.

In Fig. 344 is illustrated a diagram for producing chromatic or kaleidoscopic effects; five circuits are usually wired as indicated. This is a very attractive ornament for any sign; the design takes a different shape in variegated colours with each flash.

An attractive sign is that of the expanding star; this produces an expanding and contracting effect. The lamp-holders are wired in circular circuits; the flasher brushes operating in successive steps cause the star to expand gradually and to go off in the same way.

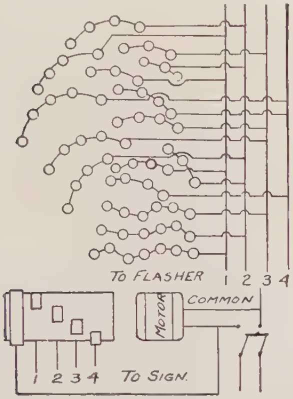

FIG. 342.—ASCENDING SMOKER.

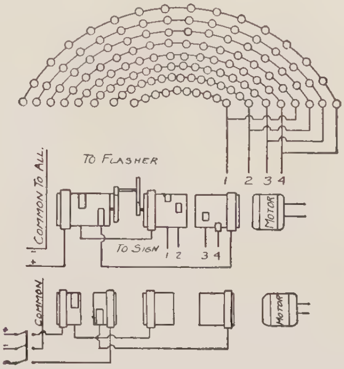

FIG. 343.—SUNRISE EFFECTS.

Figs. 345 and 346 show the circuit diagrams for two distinct types of running borders or 'chasers.' Simple rules concerning the wiring are as follows:—For two 'chasers' divide the total number of lamps by 2, *i.e.* 60 lamps divided by 2 equals 30 circuits; the lamps should be numbered 1-30 in each case; the flasher will be one with 30 brushes. For three 'chasers' divide by 3 and number from 1-20 in each case; a 20-brush flasher is required here. For four 'chasers' divide by 4 and number in each case from 1-15, etc.

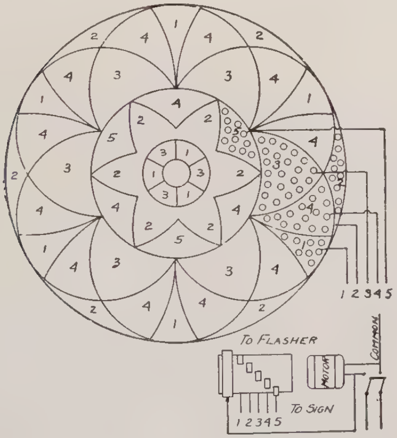

FIG. 344.—KALEIDOSCOPIC EFFECTS.

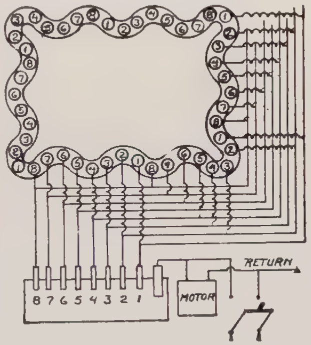

FIG. 345.—RUNNING BORDER (HORIZONTAL).

The average border will accommodate two 'chasers'; larger borders, three, four, or more.

TRAIN LIGHTING

To the credit of the late London, Brighton, and South Coast Railway is placed the first recorded attempt to illuminate a train electrically; this was in October in the year 1881, the experiment being made on a Pullman car which ran between London and Brighton. The installation consisted of twelve 'Swan' carbon-filament lamps, and a battery of thirty-two 'Faure' cells, the weight of each cell being approximately 45 lbs. The capacity of the cells was such that light was supplied for about six hours, and the battery had to be removed for charging every night.

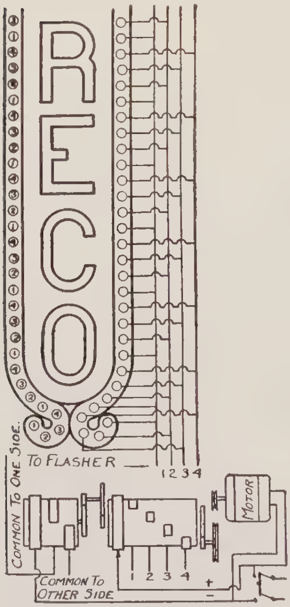

Fig. 346.—Running Border (Vertical).

The experiment was so successful that the same company, in December of the same year, equipped a complete train of four Pullman cars with twenty-nine lamps of 10 candle-power each. Later, as experience was gained, the North British, Great Northern, and London and North-Western Railways adopted electricity for illumination purposes, and so to-day this method of lighting is in general use.

It must be said that in one respect only did the carbon-filament lamp meet the exacting requirements of traction illumination: the filament would withstand to an exceptional degree the vibration which must accompany a moving vehicle. With the advent of the metal-filament lamp came the necessity for extensive research work in order to produce a lamp which would withstand high-frequency vibration in all directions of motion. The result of research in this direction is that a spiralized filament mounted in a castellated form is very satisfactory.

Polar curves showing the distribution of light in a vertical and horizontal plane, for spiralized-filament and traction-squirrel-filament lamps respectively, are illustrated in Fig. 351.

The types of lamps now generally standard on British railways are shown in the following table:—

TABLE XXVI

Volts	Watts	Bulb diameter	Over-all length	Standard cap
		VACUUM TRAIN-LIGHTING LAMPS		
16 to 30	10	50 mm.	70 mm.	B.C.
	15	50 ,,	70 ,,	,,
	20	50 ,,	70 ,,	,,
		GAS-FILLED TRAIN-LIGHTING LAMPS		
16 to 30	15	50 mm.	70 mm.	B.C.
	20	50 ,,	70 ,,	,,
	30	50 ,,	70 ,,	,,

For locomotive lighting a standard lamp is suitable for the illumination of the cab, and if headlights are required on the locomotive, as is the case on most Colonial railways, a special projection-type lamp is employed; the types are 40, 60, 150, and 200 watts. The larger sizes, when used in suitable projection lanterns, enable the driver to see clearly animals or men at distances up to about 800 feet.

Of electric lighting generally it must be said that, although the illumination of shop windows and public buildings has reached a high degree of efficiency, it must be admitted that the scientific application of light to trains has been neglected to a considerable extent. This is probably due to the fact that fittings designed for ordinary purposes have been installed in traction units apart from any consideration as to their suitability.

The principles of illumination which apply to a home or an industrial interior are entirely out of place when applied to the illumination of a railway carriage. In the design of an installation for the latter quite as much attention must be paid to the illumination of the corners of the compartment as to the centre; passengers sit in the extreme corners of compartments, whereas in the home or office, etc., one's activities are confined chiefly to the centre of the room or apartment.

Examples of incorrect lighting are apparent if one examines the general principles applied to the illumination of corridors in trains on almost every railway company's lines. It will be noticed that the lighting units consist of central fittings, with sometimes a bare lamp or a diffusing glass globe. In both cases the resultant illumination is a circular spot of light of high intensity upon the floor immediately under the unit, and the corridor between units is in comparative darkness. With such lighting one cannot see along the whole length of the corridor through alternate patches of darkness and light. From a general survey of corridor lighting we are of opinion that strip lighting from concealed sources would give satisfaction; if the corridor ceiling is painted in white with a matte surface the illumination will be evenly reflected and diffused, and none of the light will be wasted.

The illumination of railway carriages, especially of the open type such as are in use on the Metropolitan and District Railways, presents a problem to which the solutions are few; a great deal depends upon the system and units employed.

Generally speaking, the ceiling can be divided up into a number of small squares, as shown in Fig. 347, and a suitable lighting unit fitted in the centre of each square. On the other hand, the ceiling may be divided into larger squares, as illustrated in Fig. 348. This method, in effect, is similar to the system adopted for illuminating compartment coaches on some of our largest railways; the only difference is that the light sources must be of a larger candle-power. If care is not taken in the selection of the lighting units it is almost certain that shadows will be produced; clear lamps in enclosed opal shades, or white-sprayed lamps in decorative glass shades, will give good results.

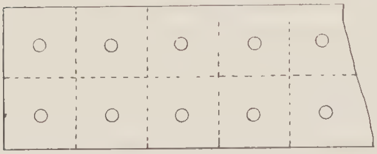

Fig. 347.—Design for Train Lighting.

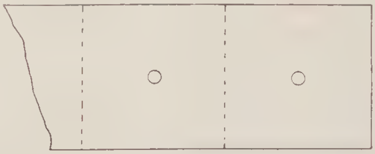

Fig. 348.—An Alternative Design.

Another method of lighting, which has recently been installed in some carriages on the underground railways in London, is illustrated in Fig. 349. The method consists of fitting a continuous trough equipped with lamps down each side of the carriage; the trough is completely enclosed, and the front is fitted with diffusing glass panels. Light is emitted through the panels, and is reflected from the ceilings and sides of the coach. This method achieves excellent results, from the fact that the illumination is well diffused and shadows are almost entirely absent.

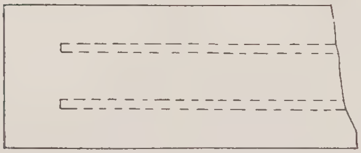

Fig. 349.—Illuminated Troughs.

Regarding types of units suitable for the illumination of railway carriages, two inexpensive but efficient units are those illustrated in Fig. 350, A; one of these illustrates a white-sprayed lamp with a clear glass bowl, and the other is an opal bowl with a clear lamp; both these units give a large amount of head-room. When a more artistic unit is desired, that illustrated at B will give the decorative effect; here two lamps in a diffusing glass globe, inclined at the angle shown, will provide even illumination.

In the illumination of lavatories and toilet-rooms the usual method of lighting is to fit a central unit with a diffusing glass globe. At times, however, when two lavatories adjoin, the bulkhead unit illustrated at C will be found to meet requirements. A hole is cut in the partition and a lamp is fitted in such a position that light from it passes into both apartments.

The illumination of dining-restaurant and similar coaches calls for both general and local lighting. The general system of lighting must be in keeping with surroundings, and not too severe. In this respect two decorative lighting units, which meet the requirements, are illustrated at D and E; these are both central units, the choice of which depends upon the construction of the coach. The illumination of the tables can best be accomplished by the use of bracket fittings, some suitable types of which are illustrated at F and G.

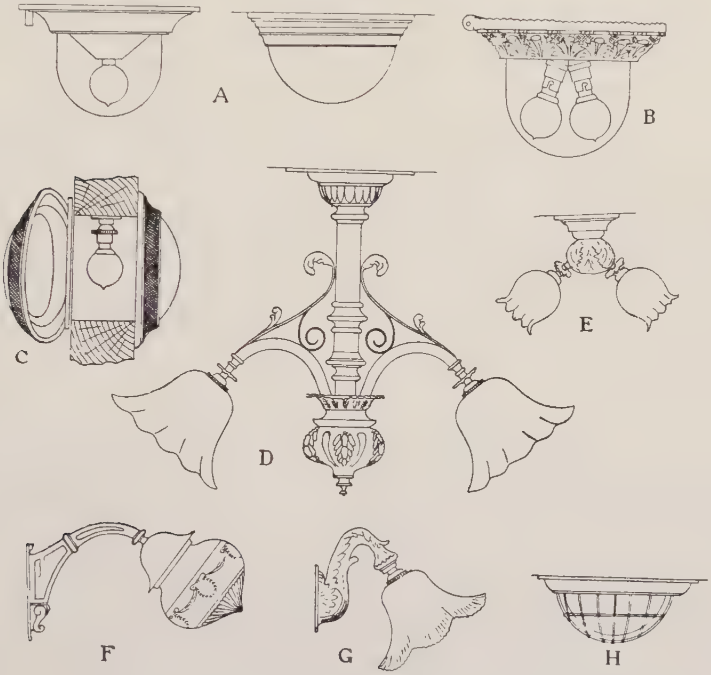

FIG. 350.—TYPICAL UNITS FOR TRAIN LIGHTING.

In the illumination of baggage and parcel vans the units fitted must allow of the greatest possible head-room; the glassware must also be protected to some extent against the possibility of breakage. A unit which meets this requirement is illustrated at H. It has a metallic base, and the bowl is protected by a metal cage which is secured to the base and locked in position.

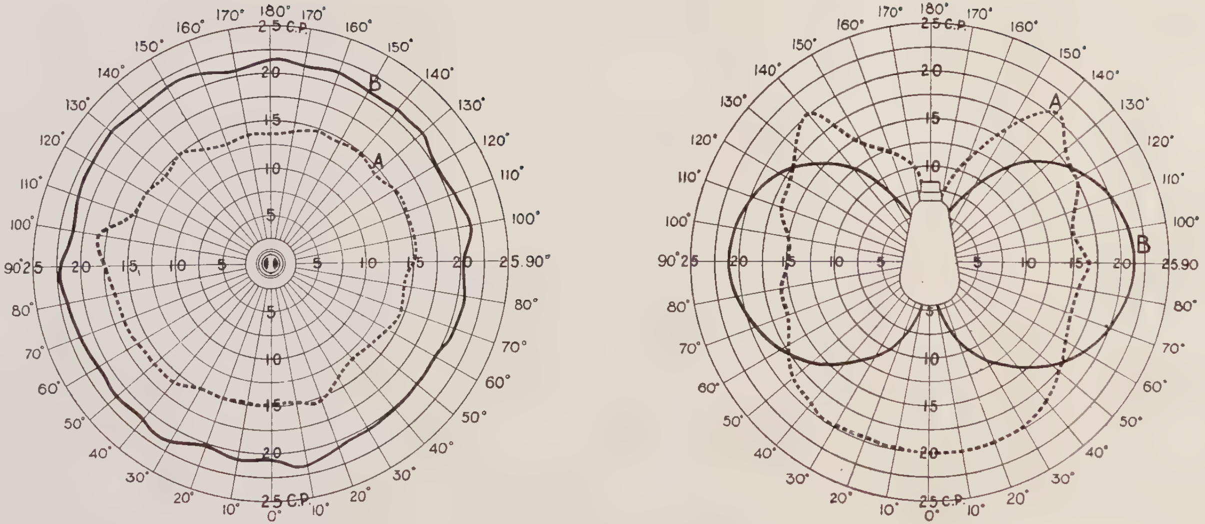

Fig. 351.

Polar Curves showing Distribution of Light in a Horizontal Plane.

A.—120-volt, 30-watt spiralized filament lamp.
B.—120-volt, 30-watt tractor squirrel-cage filament lamp.

Polar Curves showing Distribution of Light in a Vertical Plane.

A.—120-volt, 30-watt spiralized filament lamp.
B.—120-volt, 30-watt tractor squirrel-cage filament lamp.

CHAPTER XIV

MISCELLANEOUS

Cathedral Lighting—Special Lighting Units—Light Control—Antique Lighting Units—Temporary Outside Lighting—Drawing-Office Lighting—Office Lighting—Illumination Data.

THE illumination for church and cathedral interiors should have the qualities of restfulness. A poorly designed lighting system affects both the minister and his congregation. He gazes into glaring lights instead of into the faces of his parishioners. They, in turn, suffer from eye-fatigue, drowsiness, and headaches, caused by those same improperly concealed lamps, and, because of this irritation, fail to sustain an interest in the service.

On the other hand, good lighting in the church means an attractive church and an attentive congregation. As an example of good lighting in a place of worship we cannot do better than give, as a model, details of the recent installation at Peterborough Cathedral.

Peterborough Cathedral was built about 800 years ago, and, although parts of the fabric are more recent, the interior is almost pure Norman.

The new lighting system was formally inaugurated on 4th October 1925. Before that day the cathedral had been for many years lighted by means of gas. It would be difficult to conceive of a more complete transformation in the appearance of an interior than has been effected by the new system of illumination in Peterborough Cathedral. Whereas before the introduction of electric lighting the omnipresent gloom had merely been emphasized by hundreds of flickering points of gaslight, the interior is now bathed in a mellow radiance proceeding from the invisible sources. The effect is remarkably impressive, and, what is more, is entirely in keeping with the character and appearance of the cathedral.

Owing to the fact that the lighting units for the most part are situated on either side of the clerestory windows, the light is in respect of direction and distribution similar to daylight. Shadows are few, and are of the depth and distribution of those cast by the sun.

One notable effect of the new lighting is the manner in which it reveals and emphasizes the architectural and decorative features of the interior. Formerly these could not be seen at all at night. Now the whole cathedral is suffused with a light which illuminates the beautifully carved roof as well as the famous mosaic pavement. A comparison of the photographs taken by daylight and by the new electric lighting will demonstrate the close similarity which exists between the natural and the artificial illumination.

The Origin of the Scheme.—Early in 1924 the Dean and Chapter requested Mr. H. A. Nevill, the Peterborough city electrical engineer, to submit proposals for the illumination of the cathedral by means of electricity.

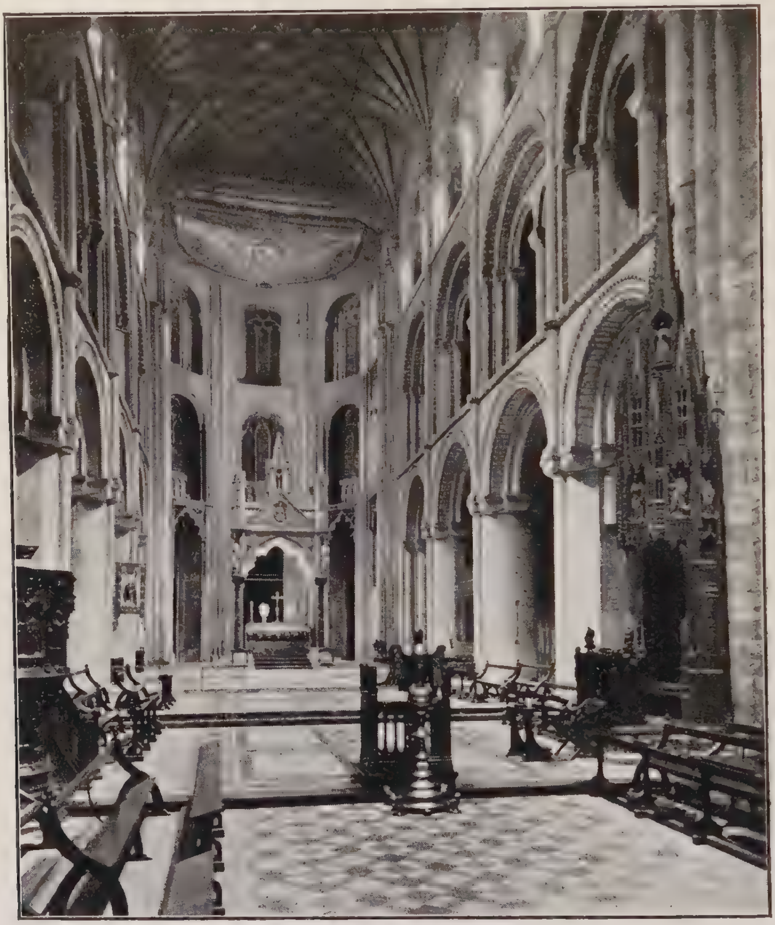

Fig. 352.—The Nave.

After collaboration with the illuminating department of the British Thomson-Houston Co. Ltd., Mr. Nevill submitted a proposal to the Dean and Chapter in August. This scheme was carefully considered, and, as it appeared likely to meet the requirements of the case, it was arranged to erect a small trial installation so that the actual effect could be judged. This trial installation was duly completed in December, and was considered generally satisfactory, although a few minor alterations were made in the position of the lighting units to meet the views of the cathedral architect. Finally, the proposals for the lighting of the nave, choir, chancel, and transepts were approved on the basis of the trial installation, and this scheme was eventually completed and inaugurated on Sunday, 4th October 1925.

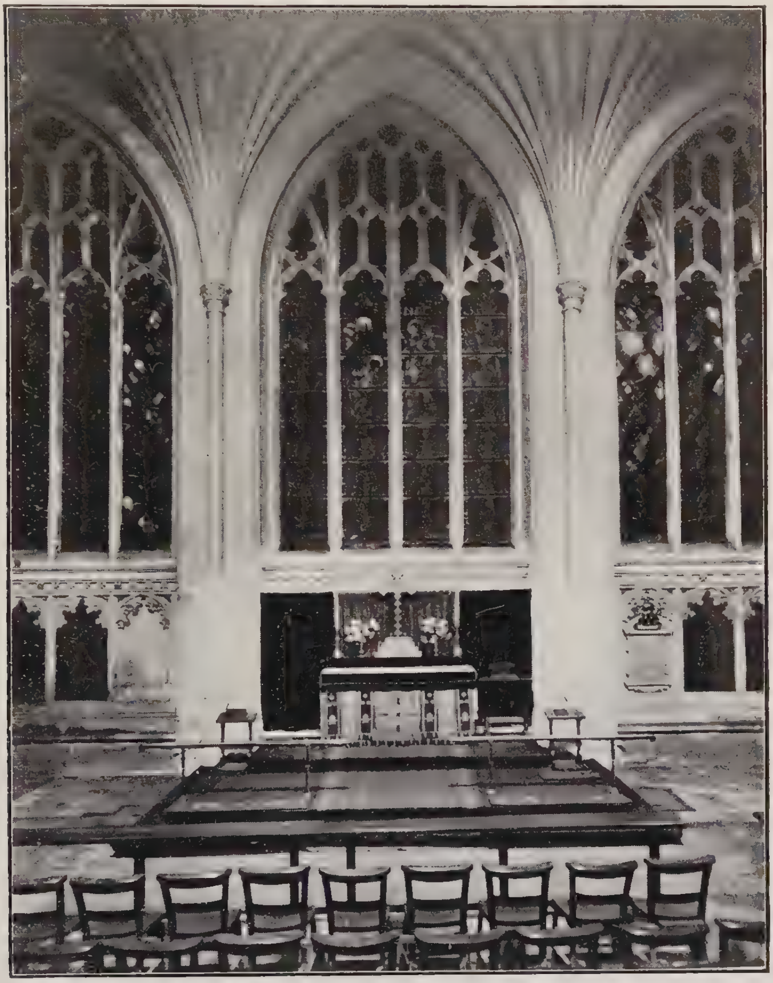

Fig. 353.—The Chancel.

The cathedral has a cruciform ground-plan, consisting of nave, two aisles, chancel, and transepts. The chancel, nave, and transepts have each three stages, namely, arcading, triforium, and clerestory.

The greater portion of the lighting is effected by units placed on either side of the clerestory windows—so that the artificial light comes from practically the same direction as the daylight, and the units, being placed at a considerable height above the floor, are beyond the normal angle of vision. Furthermore, as they are fixed in recesses they are practically concealed from view up and down the length of the building. The units are suitably grouped together and controlled

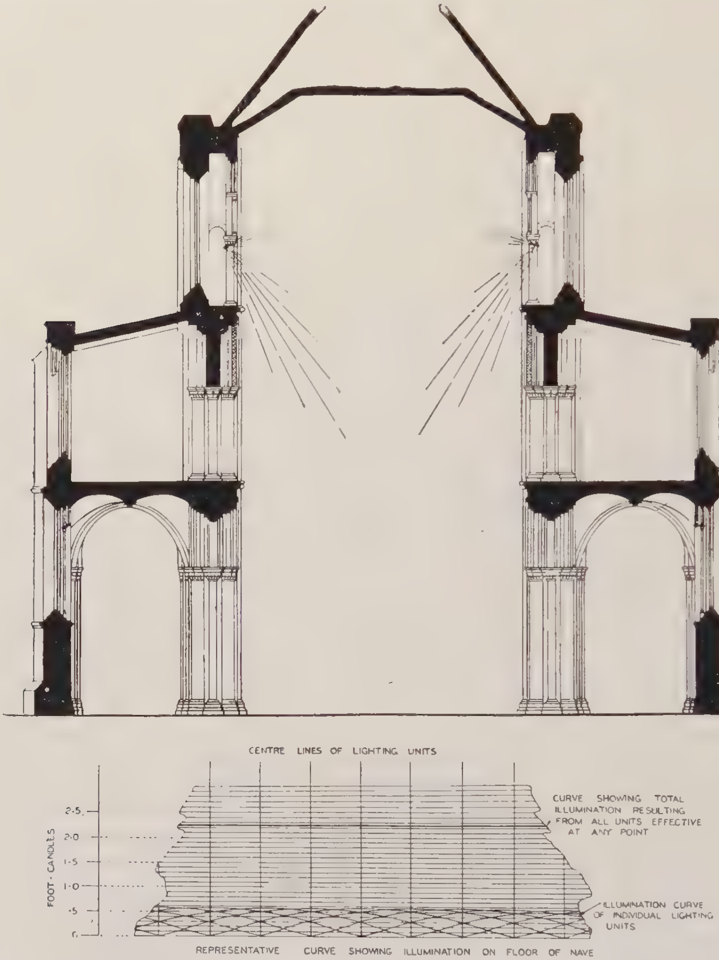
CENTRE LINES OF LIGHTING UNITS
FOOT-CANDLES
2·5
2·0
1·5
1·0
·5
0
CURVE SHOWING TOTAL ILLUMINATION RESULTING FROM ALL UNITS EFFECTIVE AT ANY POINT
ILLUMINATION CURVE OF INDIVIDUAL LIGHTING UNITS
REPRESENTATIVE CURVE SHOWING ILLUMINATION ON FLOOR OF NAVE

Fig. 9.

Curve showing theoretical distribution and intensity of illumination on floor level.

Fig. 354.—Section of Cathedral, showing Position of Units.

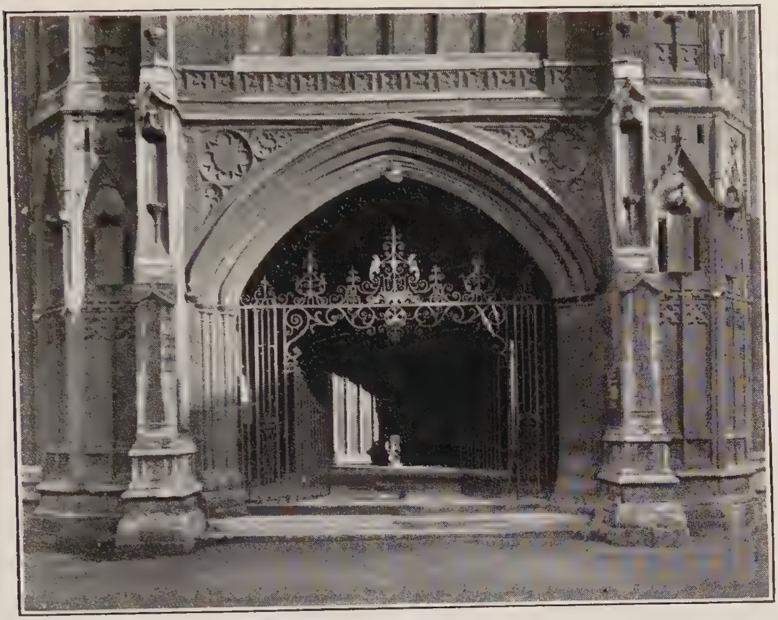

FIG. 355.—WEST PORCH (DAY).

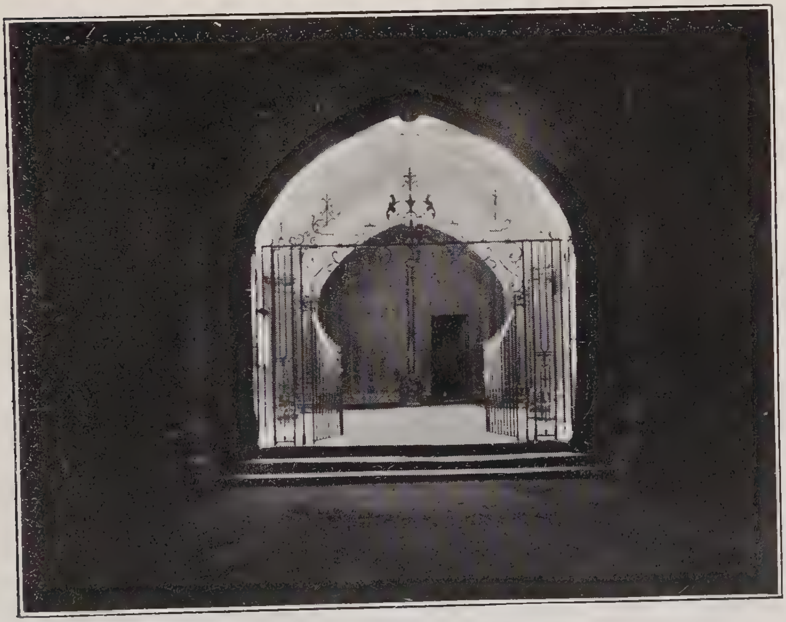

FIG. 356.—WEST PORCH (NIGHT).

by contactor switches placed in the triforium in the north and south transepts. These contactors in turn are controlled by push-button panels placed immediately behind the choir stalls on the south side. The contactor panels on the north and south sides respectively are fed from the two sides of a 400-volt, 3-wire, direct-current supply from the Corporation electricity works.

Special Lighting Units.—Each lighting unit consists of a specially designed projector comprising three silvered-glass mirrors mounted in a suitable case, and equipped with a 250-watt projector-type gas-filled lamp. The lamp is supported in a porcelain holder mounted on an adjustable bracket, so as to permit of its being correctly focussed in relation to two of the mirrors, the third mirror being itself adjustable.

The projector itself is mounted on an adjustable arm, which in turn slides on a bracket attached to the wall of the building. This bracket is jointed, so that by releasing a screw the complete projector can be swung into a position whence it can be easily reached from the walk which runs round the clerestory, for cleaning, etc., without the use of ladders or scaffolding.

The beams from these projectors are trained diagonally downwards across the cathedral towards the bottom of the piers on the other side of the nave. The portion of the beams which would otherwise be split on the edge of the clerestory is deflected upwards to illuminate the upper part of the walls and roof.

Different arrangements were necessary at the 'crossing' beneath the central lantern tower. Here eight special units are mounted nearly 100 feet above the floor. Each of these units is provided with a single silvered-glass reflector, and a device to prevent the light 'splashing' on the walls in the upper part of the tower. These units are supported on tubular arms which are carried from a pivot attached to the wall of the building, and are provided with a counterbalance weight so that the units themselves, which project some considerable distance beyond the masonry, not only can be swung round to an accessible position for cleaning, but can also be adjusted in all directions from this position.

The lighting at the eastern end of the apse, and certain other situations, is effected by Mirolux trough reflectors fixed in a suitable position in the triforium and clerestory.

All the lighting units are finished in light buff tint, matching the colour of the walls, so as to render them as inconspicuous as possible.

The electric supply enters the building at the ends of the north and south transepts, where the main switches, meters, etc., are situated, and passes thence, by means of lead-covered cable, up the staircase at the end of the transepts to the control panels which are situated at the extreme north and south ends of the east side of the transepts on the triforium level. From these points lead-covered cables run up the staircase to the clerestory level to their respective units.

How the Lighting is Controlled.—Special wall lanterns are employed for the illumination of the vestries, and the entrance in the west porch is lighted by means of units secreted in the paving. The light from these units is thrown upwards on to the vaulting, whence it is diffused over the entrance-way to the west doors. Special arrangements are employed to prevent the lamps from being seen in passing from the porch to the cathedral, or *vice versa*.

Attention is drawn to the day and night illustrations of the west porch ; here we see an example of artificial illumination being preferable to daylight. When the right-hand side door is open during daytime, extreme light contrasts exist, and the architectural features of the porch cannot be seen. When artificially illuminated, the whole of the porch can be seen bathed in even illumination, and the whole of the architecture is prominent.

ANTIQUE LIGHTING UNITS

Almost without exception the old-time lighting units are very artistic and decorative ; some of them are real works of art, especially those which were manufactured in the wrought-iron period. One of the authors *discovered* the three units illustrated on page 398. After careful investigation it was ascertained that the units, without exception, were first used with oil as an illuminant, then gas, and now they are equipped for electric light.

In the units illustrated no fault can be found from a decorative point of view ; there is, however, a distinct fault from an efficiency of illumination point of view. We are not referring to the fact that the units are not fitted with reflectors and are therefore inefficient. It is possible that the quantity of light from the units is adequate for their purpose, but the clear lamps should be removed and replaced by white-sprayed lamps.

In all three cases the units are used to illuminate the steps leading into important buildings. There is nothing more conducive to accidents than the ‘ raw light ’ which must strike the eyes each time the units are passed.

TEMPORARY OUTSIDE LIGHTING

When such work as excavating is being carried out, it is necessary, at times, to work in shifts throughout the twenty-four hours of the day ; this necessitates the use of artificial light at night-time. Such lighting is termed temporary lighting, and the requirements to be met are that the light should be abundant, free from glare, and evenly distributed.

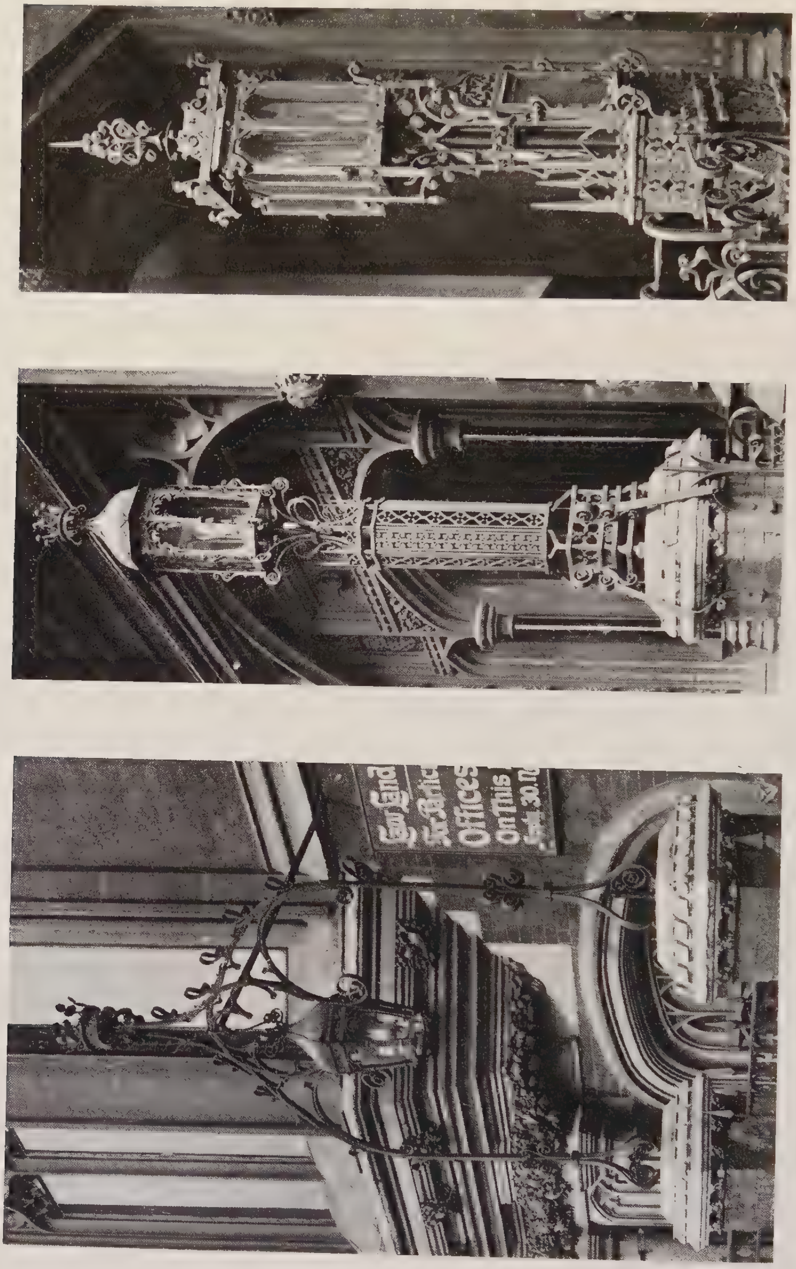

FIG. 357.—ANTIQUE LIGHTING UNITS ADAPTED TO MODERN REQUIREMENTS.

Temporary lighting on a large scale is illustrated in Figs. 358 and 359; here day and night views are shown of a portion of the excavation works for the Morden extension of the Underground Railways, London. In the day illustration a few of the lighting units in this installation can be seen; these are floodlight projectors and dispersive-type units.

The floodlights were used in positions where a high intensity of light was necessary, and the dispersive-type units were called upon to provide light of low intensity in certain areas. From the night illustration it will be seen that this combination of units, considering the rough nature of the ground, is successful.

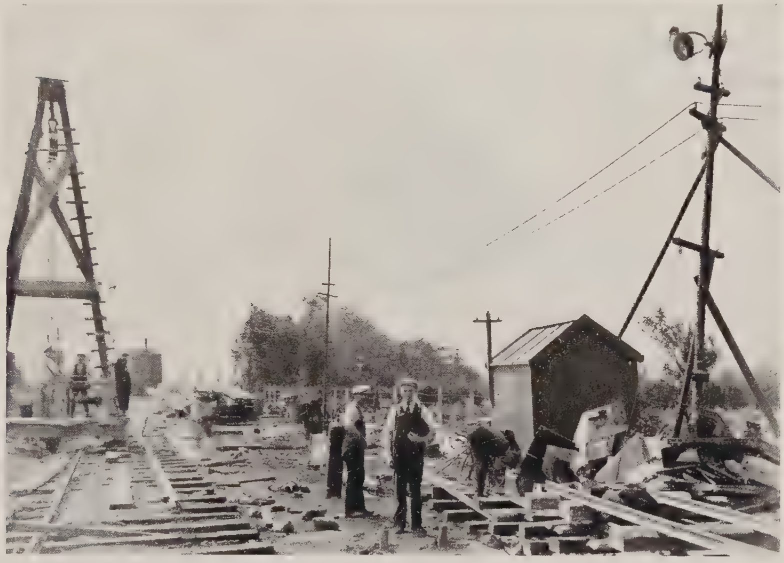

Fig. 358.—Showing a Method of Temporary Lighting at the Morden Extension of the Underground Railway.

Temporary lighting is not confined to outside use by any means; this is apparent from Fig. 360, which illustrates the temporary installation fitted inside the theatre at Luna Park, Tottenham Court Road; the installation comprises a number of white-sprayed lamps equally spaced round wooden bands. To each band are fitted four lamps; the conductors from each are paralleled and the whole connected to a temporary switchboard. For the stage lighting a number of acting-area floods were used in conjunction with footlights of red, white, and blue lamps. The general effect was quite satisfactory.

The effectiveness of this type of temporary unit is further illustrated in Fig. 361, which shows the interior of the refreshment-room at Luna Park. Considering the number of units used, and the temporary nature of the installation, it must be said that the results are pleasing.

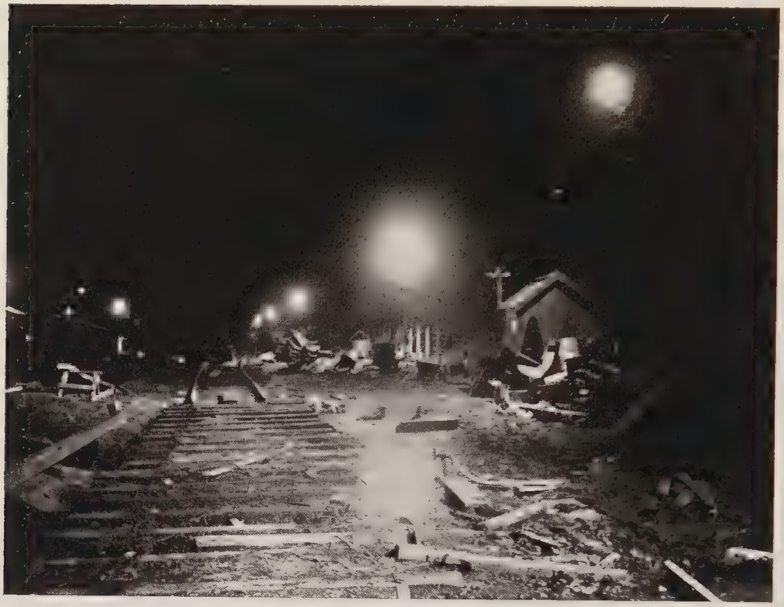

Fig. 359.—The Effect of the Installation illustrated in Fig. 358.

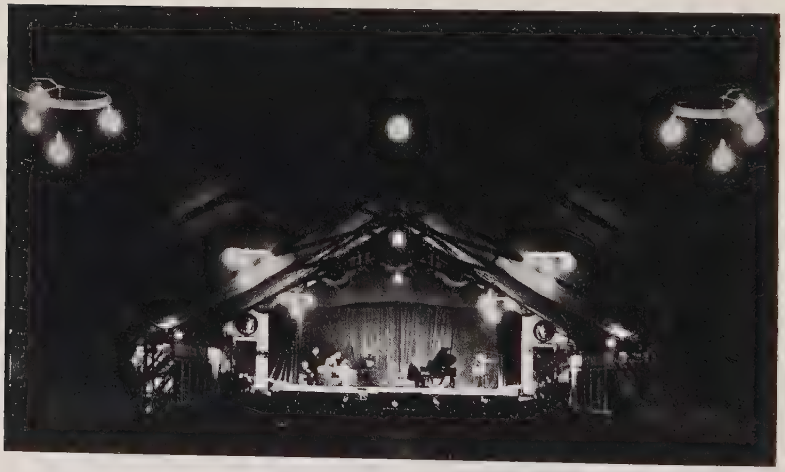

Fig. 360.—Excellent Stage Lighting obtained through Temporary Measures.

DRAWING-OFFICE LIGHTING

In no part of an engineering works is good lighting more essential than in the drawing-office. Not only must the intensity of the lighting be adequate, but glare and harsh shadows must be avoided. Glare is the defect which is most difficult to avoid when the intensity is raised to the value necessary for easy and efficient working; but there is really no reason why high intensities should not be glareless.

Drawing-offices may appear over-lighted, and the draughtsman may suffer eye-strain. When, however, comparisons are made between the actual foot-candles obtained from the artificial source of lighting on the working plane, and the average daylight intensity usually existing, it is found that the artificial light intensity is not 1 per cent. of the daylight intensity, even if there be no sunlight in the room. The eye-strain in this case is attributable to the glare of the artificial sources of light, and is caused by placing inefficient diffusing units too near the working plane. With brilliant patches near the worker and spaces of semi-darkness between tables and boards, the eye has constantly to adjust itself, and the workers suffer eye-strain, fatigue, and general depression. But if properly spaced and properly designed diffusing units are employed, an even intensity of light can be obtained over the whole area, and eye-strain is eliminated.

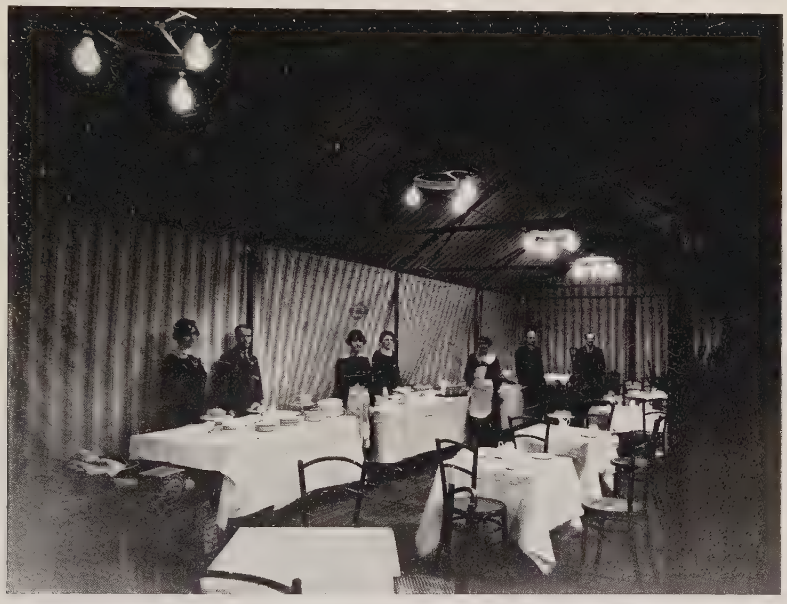

Fig. 361.—Temporary Lighting in Refreshment Room, Luna Park.

Experience has shown that in drawing-offices, above all places, an adequate quantity of soft and well-diffused light must be provided if discomfort is to be avoided. There should be no extreme contrasts in the brightness of objects within the field of vision, and shadows should be soft and luminous or entirely absent. Moreover, the lighting system should be designed to allow flexibility in the arrangement of the drawing-office equipment, and should be easy to maintain, otherwise decreased efficiency will result.

TABLE XXVII

LOCATION	ILLUMINATION IN F.C.S.	HEIGHT OF W. PLANE ABOVE FLOOR LEVEL	LOCATION	ILLUMINATION IN F.C.S.	HEIGHT OF W. PLANE ABOVE FLOOR LEVEL	LOCATION	ILLUMINATION IN F.C.S.	HEIGHT OF W. PLANE ABOVE FLOOR LEVEL
A	27	3′-0″	J	21	3′-0″	V	20	3′-0″
B	24	3′-0″	K	24	3′-0″	W	21	3′-0″
C	23	3′-0″	L	24	3′-0″	X	23	3′-0″
D	26	3′-0″	M	24	3′-0″	Y	21	3′-0″
E	32	3′-0″	N	23	3′-0″	Z	24	3′-0″
F	8	3′-0″	P	21	3′-0″	α	14	3′-0″
F′	7	3′-0″	Q	14	3′-0″	β	21	3′-0″
G	16	3′-0″	R	16	3′-0″	γ	27	3′-0″
H	26	3′-0″	S	21	3′-0″			
H′	18	3′-0″	T	20	3′-0″			
H″	13	3′-0′	U	28	3′-0″			

ALL READINGS TAKEN ON WORKING PLANE

Centre of Drawing Boards

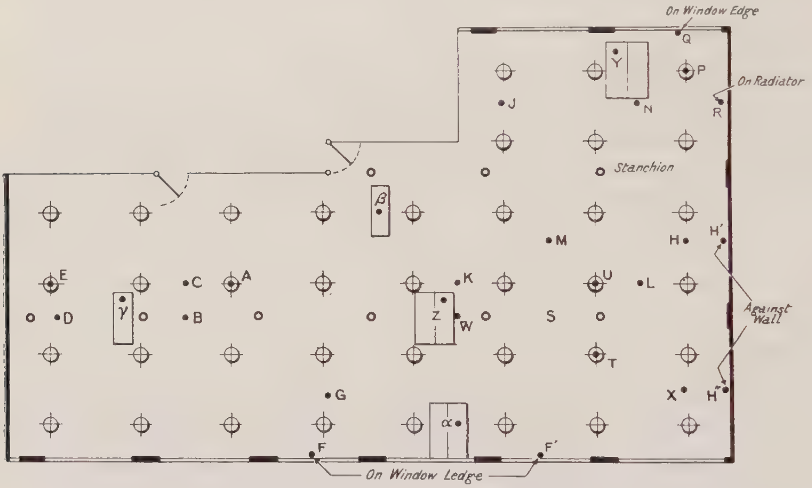

Fig. 362.—Plan of Drawing-Office.

In the design of the lighting equipment for the drawing-office illustrated in the plan in Fig. 362 all the above factors were taken into account. The building is L-shaped, the dimensions being 92 feet long by 37 to 56 feet wide. It will be noted that the windows from which daylight is obtained are all on one side of the office, and the desks situated at the extreme distance from the windows are very inefficiently lighted during the hours of daylight, thus necessitating the assistance of artificial light. The lighting installation is composed of thirty-eight lighting units (Fig. 363).

Each unit (Fig. 364) has a housing composed of white enamelled steel, with a vitreous white enamelled steel reflector, designed to meet drawing-office requirements, the light being diffused by a special 'Superlux' bowl. Each unit is capable of accommodating a 1,500-watt gas-filled lamp, but in this particular case 500-watt lamps are employed. These units are mounted at a height of 8 feet 6 inches above the working plane, which is 3 feet above the floor. The spacing of the units is 9 feet 6 inches by 12 feet. When all the lighting units are in operation the energy consumption is 19 kilowatts; and as the total floor area is 4,136 square feet, the energy consumption per square foot of floor area is 4·6 watts, the watts per superficial foot per mean spherical candle-power being 0·208. It was estimated when the installation was designed that an average illumination of 20 foot-candles would be obtained, and tests

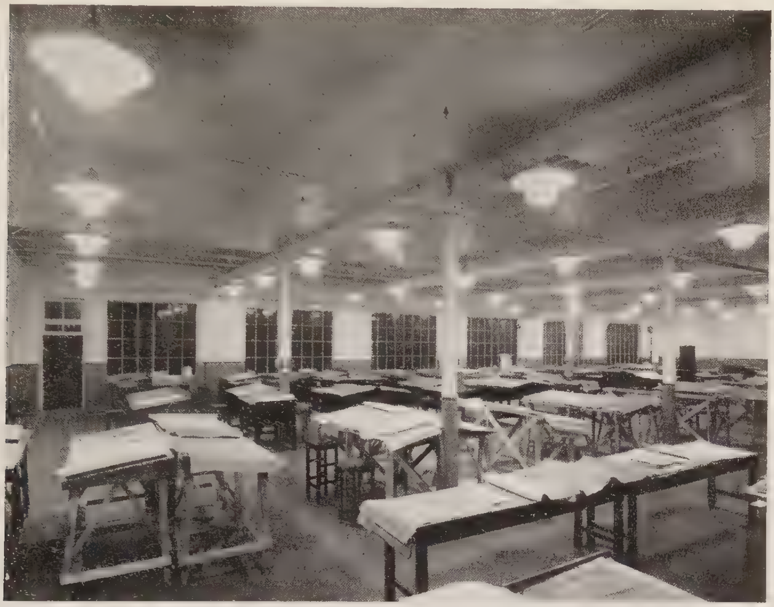

Fig. 363.—The 'Effect' of the Installation described.

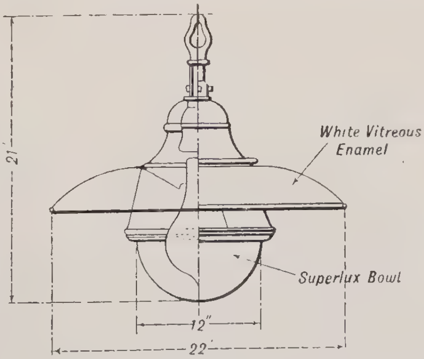

Fig. 364.—The Unit used in this Installation.

carried out after the work had been completed showed that the average intensity was 22·1 foot-candles. The readings taken at various points are shown in the table at the top of the plan (Fig. 362).

OFFICE LIGHTING

In the design of a lighting installation for a general office a considerable amount of inconvenience may be caused if correct methods of design are not adopted in the first place. In such installations there is a tendency to fit units in positions where it is *thought* they will give the best service.

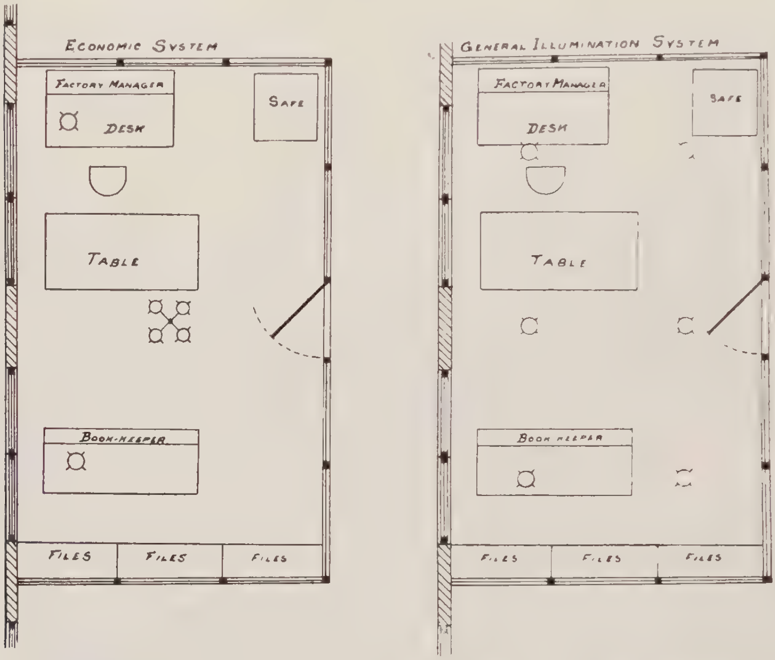

Fig. 365.—Wrong and Right Methods of Design for Office Lighting.

This is incorrect, because at times it becomes necessary to move office furniture to other positions, and therefore the installation does not meet the new requirements.

In Fig. 365 is illustrated an office interior with two different systems of lighting. In one case a central unit provides the majority of light in the centre of the office, with two local lights; in the other case a general system of illumination is adopted. It will be seen that the latter system is preferable, not only because the illumination is more even, but because any changes in the position of the office furniture will not affect the efficiency of the system.

ILLUMINATION DATA

DEFINITION OF THE UNITS, TERMS, AND QUANTITIES USED IN ILLUMINATING ENGINEERING, WITH THE LAWS GOVERNING THE REFLECTION AND TRANSMISSION OF LIGHT

Absorption.—When light is incident on the surface of a material of any kind, a portion of it is transformed into heat and thus lost as light. The remainder is either reflected or transmitted, or portions of it are both reflected and transmitted.

All materials possess this power to some extent. Those materials having low absorption receive most favour as reflecting and transmitting media.

Acuity.—(See Visual Acuity.)

Ampere.—The ampere is the unit of electric current, and is defined as the current that will electrolytically deposit silver at the rate of ·001118 gram per second. Amperes equal watts divided by volts.

Angle of Incidence.—The angle which a ray of light striking a surface makes with the normal to that surface.

Angle of Reflection.—The angle with respect to the normal at which a ray of light leaves a surface after it has been reflected.

Apparent Candle-Power.—Candle-power at a distance *d* is the candle-power of the simple luminous source which at the distance *d* from the point of observation would give an illumination equal to the observed illumination.

The term should be used only for cases in which the law of inverse squares does not apply. The term is meaningless unless the value *d* is given.

Beam Candle-Power.—The beam candle-power produced by searchlights, projectors, or lenses refers to the candle-power in the direction of maximum intensity.

Brightness.—The brightness of a surface giving off light is expressed in terms of the *Lambert.*

Bulbs.—Lamp bulbs are made in four distinct types : the straight-sided, the pear shape, the round or spherical, and the tubular or cylindrical.

Candle-Power.—Candle-power is a measure of luminous intensity, a term used to express the intensity of light emanating in any given direction from a light source. It is analogous to steam pressure in steam engineering and voltage or electro-motive force in electrical engineering.

Measurement of candle-power is not made directly, but is obtained by comparing with standards of known candle-power, kept in the National Laboratories of France, Great Britain, and the United States.

The present unit of candle-power is referred to as the *International Candle.* The following table gives the relation existing between the units in use at the present time :—

One International Candle=one American Candle.
One International Candle=one French Candle, called *Bougie Décimale.*
One International Candle=one English Candle, called *Pentane Candle.*
One International Candle=1·11 German Candle, called *Hefner.*

The abbreviation for candle-power is c.p.

Candle-power equals the total watts divided by *watts per candle*. Unless otherwise specified, candle-power and watts per candle refer respectively to the *mean horizontal candle-power* and the *watts per mean horizontal candle-power*.

Candle-Power Rating.—In the case of some classes of incandescent lamps, especially those for street series lighting, the sizes are rated in mean horizontal candle-power.

Carbon Lamp.—This was the first commercial incandescent lamp, invented and introduced by Thomas A. Edison in 1879. The filament was horseshoe-shaped and made of carbonized paper. It had an efficiency of about 7 watts per candle. Later the filament was made of carbonized bamboo and the efficiency raised to about 4·8 watts per candle. The present carbon filament lamps have an efficiency of about 3 watts per candle and a useful life of about 450 hours. The demand for carbon lamps is rapidly decreasing.

Characteristic Curves.—A curve which expresses the relation between two variable properties of a luminous source, such as candle-power and volts, candle-power and rate of fuel consumption, etc.

Coefficient of Absorption.—This absorption factor is the ratio of the amount of light absorbed by a body to the amount of light incident upon it. The percentage depends upon the nature of the surface of the medium as well as the angle of the light and the *angle of incidence*. (See Absorption.)

Coefficient of Reflection.—The ratio of a total luminous flux reflected by a surface to the total luminous flux incident upon it. In the case of mixed regular and diffuse reflection the coefficient may be divided into its component parts.

The coefficient of *diffuse reflection* is the ratio of the luminous flux reflected diffusely to the total flux.

The coefficient of *regular reflection* is the ratio of the luminous flux reflected regularly to the total flux.

Coefficient of Transmission.—The ratio of the total luminous flux transmitted to the total luminous flux incident on the surface.

Colour.—Colour is the sensation produced in the eye by reason of the wave-lengths or rate of vibration of the light rays. The true colour of a body is its daylight colour. The apparent colour may change when the body is illuminated with light of different colours. The colour of different objects is generally due to their ability to absorb certain wave-lengths of light and reflect others: for example, a body which absorbs red rays and reflects blue and yellow rays appears green.

Current.—The rate of flow of electricity in a conductor. Current is measured in *amperes*.

Diffusion.—Light is said to be diffused when by process of *reflection* and *refraction* it reaches the eye from many directions rather than from the direction of the source. It is usually secured by the interposition of opal or frosted globes or by the use of reflectors whose surface is corrugated or dulled. Diffusion is accomplished at some sacrifice in light intensity. The seeing value of the light is improved, however, and glare reduced.

When a light ray strikes a reflecting surface and the reflected light rays are scattered in all directions, the reflection is *diffuse.* A perfectly diffuse surface follows the law —*The intensity in every direction is proportional to the cosine of the angle of emission measured between the beam of emission and the normal to the surface.*

A rough surface of plaster of Paris, the dull surface of dense opal glass, and the ordinary dull-finish plaster ceiling are very good examples of diffusers.

Diffuse Reflection.—Reflectors which give a diffuse reflection include all of the opal or white glass reflectors and all of the porcelain enamelled reflectors. These reflectors afford only limited possibilities in the control of light. They may efficiently redirect light, but changes in their shape do not redirect the light in definite directions in desired proportions. It is impossible to make a concentrating reflector of diffusely reflecting surfaces. Such surfaces can only redirect light in a general downward direction. Opal glass reflectors, in addition to reflecting light, transmit light, the quantity of which depends on the density of the glass employed.

Distribution Curve —A polar diagram showing graphically the distribution of light given out by a source.

Effective Lumens.—The total number of lumens incident on the working plane. This value may be obtained by multiplying the area of the *working plane* by the average illumination in *foot-candles.*

Effective Lumens per Watt.—The effective lumens of a given area divided by the total watts of the lamp illuminating the area is called effective lumens per watt. This term differs from the efficiency of utilization in that it takes account of the efficiency of the lamp, and for this reason is often called the gross efficiency.

Efficiency of Lamps.—Lamp efficiency is expressed in terms of the ratio of lumen output to power input. The rated efficiency of lamps is now preferably expressed in *lumens per watt,* instead of in watts per spherical candle-power or watts per horizontal candle-power. A lamp having a specific output of 20 lumens per watt is twice as efficient as one producing but 10 lumens per watt.

Efficiency of Utilization.—The percentage of total lumens emitted by the lamp that reaches the working plane. The value expresses the illuminating efficiency of any given system. In other words, the number of lumens which are effective or usable on the work, or for the lighting of an object, expressed as a per cent. of the total lumens delivered by the lamps, is called the efficiency of utilization. This term is entirely independent of the lamp efficiency, and is frequently called the net efficiency.

Flux of Illumination.—The flow of radiant energy from a light source. This flux is measured in *lumens.* For a light source the total flux is the total emanation of light from the source. For an area the total flux of illumination is equal to the intensity of the illumination multiplied by the area over which it is distributed.

Foot-Candle.—The unit of intensity of illumination. It is equal to the illumination falling upon a surface one foot distant from a one-candle-power source. If a uniform point source of one candle-power is placed at the centre of a sphere of one foot radius, every point on the inner surface of the sphere receives an illumination of one foot-candle. This is apparent from the fact that the area of this unit sphere is 12·57 square feet, and a uniform point source of one candle-power emits 12·57 lumens. Hence, one lumen per square foot gives an average intensity of one foot-candle.

Glare.—Glare is a condition of bright light sources or illuminated surfaces which results in ocular discomfort or interference with vision. In Fig. 366 are illustrated the eyes of one of the authors; the photographs were taken under glaring light conditions, and under light which was even and well diffused. At A the discomfort can be clearly seen. The iris is almost closed and the muscles of the eye are strained in an effort to shut out the blinding glare. At B the eye is restful, the iris is wide open, and vision is comfortable.

Globe.—A globe is an enclosing appliance of clear or diffusing material, the chief use of which is either to protect the lamp or diffuse the light.

Hemispherical Candle-Power.—(See Mean Hemispherical Candle-Power.)

Horizontal Candle-Power.—(See Mean Horizontal Candle-Power.)

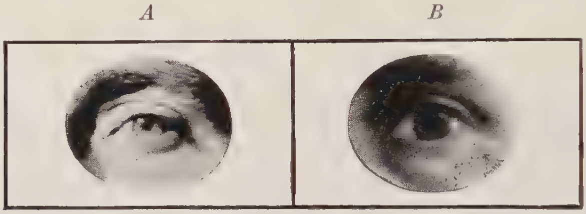

Fig. 366.

Horizontal Distribution Curve.—A polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane perpendicular to the axis of the unit, and with the unit at the origin.

Hue.—Hue is that property of colour by which the various spectral regions are characteristically distinguished. All colours except purples and whites may be matched in hue with spectral colours. In the case of a purple, the spectral hue which is complementary to the hue of purple is ordinarily used for scientific designation.

Illumination.—The term illumination is often used to indicate the luminous radiation falling upon a surface in contradistinction to light as luminous radiation emitted from a light source. The *intensity of illumination* is measured in foot-candles, and *flux of illumination* in lumens.

Illuminometer.—An instrument used for measuring the intensity of illumination. This instrument is sometimes called a portable photometer.

Incidence.—(See Angle of Incidence.)

Intensity.—A measure of luminous radiation in any direction without reference to area. *Intensity of light* is measured in candle-power, and the *intensity of illumination* in foot-candles.

Intrinsic Brilliancy.—A measure of the brightness of light-emitting surfaces, expressed in candle-power per square inch, also expressed in lumens per square inch and lumens per square centimetre.

Kilowatt.—A kilowatt is the equivalent of 1000 watts, a unit of electrical power. One horse-power is equal to 0·746 kilowatt.

Kilowatt-Hour.—The kilowatt-hour is the unit of electrical energy, and is represented by the expenditure of one kilowatt in one hour. Hence, to obtain the kilowatt-hours of any circuit for a given period of time, multiply the kilowatts by the time in hours. The watt-hour is 1-1000 part of the kilowatt-hour.

Lambert.—The lambert is the practical unit of brightness. It is equal to a brightness of $1/\pi$ candles per square centimetre of projected area. It is the average brightness of a surface emitting or reflecting one lumen per square centimetre, or the uniform brightness of a perfectly diffusing surface emitting or reflecting one lumen per square centimetre.

Law of Inverse Squares.—Unless modified by some interfering agency, light rays travel in straight radial lines in all directions from the source. The law of inverse squares follows directly from the fact :

The intensity of illumination received by a surface from a light source is directly proportional to the candle-power, and inversely proportional to the square of the distance.

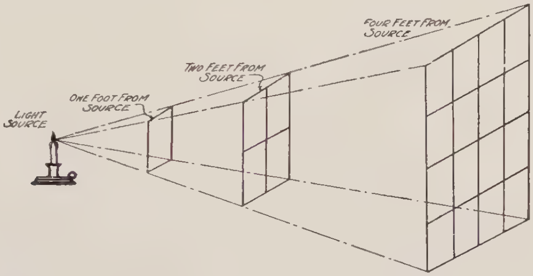

Fig. 367.—Diagram illustrating the Law of Inverse Squares.

For instance, at one foot from a lamp giving 16 candle-power the intensity would be 16 foot-candles ; at 2 feet, 4 foot-candles ; and at 4 feet, 1 foot-candle.

Life of Lamps.—The total life of a lamp is the period of time that it will operate before it ‘ burns out.’

The useful life of an incandescent lamp is given as the number of hours which this lamp will burn before its candle-power is reduced 20 per cent.

Light-Distribution Curves.—The intensity of light in candle-power from a source is indicated by a light-distribution curve. The intensities corresponding to various angles of emission, about either the horizontal or vertical axis, are plotted in polar co-ordinants. (See Distribution Curve.)

Lumen-Hours.—The lumen-hour is the unit of luminous energy, and is defined as the quantity of luminous energy which would be emitted in one hour from a unit having a total luminous flux of one lumen.

Hence, the total lumen-hours for any light source operating a given length of time is equal to the total lumens of the source multiplied by the time in hours.

Lumens per Watt.—The efficiency of an incandescent lamp may also be expressed as lumens per watt. Effective lumens per watt is a measure of the efficiency of a lighting installation, and equals the total effective lumens divided by the total watts input of all units, equals mean foot-candles divided by watts per square foot.

Luminosity.—A term which expresses the brightness of a surface from which light arises as the result of either diffusion or emission.

The luminosity of the diffusely reflecting medium is expressed as the illumination of the body multiplied by the reflection coefficient; likewise the luminosity of a diffusely transmitting surface, such as dense opalescent glass, is the illumination incident on the surface multiplied by the coefficient of transmission.

Luminous Efficiency.—The luminous efficiency of any light source is the ratio of the luminous flux to the radiant flux from the source, and is expressed in *lumens per watt.*

Luminous Intensity.—The intensity with which light flux is emitted in any direction.

Mean Hemispherical Candle-Power.—The average of the intensities of a given light source in all directions of the lower hemisphere or upper hemisphere as the case may be.

Mean Horizontal Candle-Power.—The average of all of the candle-power values lying in a horizontal plane passing through the luminous centre of the lamp.

The mean horizontal candle-power cannot satisfactorily be used to indicate the light output of other than vacuum incandescent lamps and lamps without concentrated filament. Because of this limitation it is being superseded by ratings dependent directly upon the total light emitted.

Mean Spherical Candle-Power.—The average candle-power of a lamp in all directions in space. The mean spherical candle-power bears a definite relation to the total flux of light from the lamp, and is, therefore, sometimes used as a measure of that quantity.

Millilambert.—Is 1-1000 part of a lambert.

Normal Brightness.—The normal brightness of an element of a surface is the brightness taken in a direction normal to the surface. Normal brightness is sometimes called the specific luminous intensity.

Ohm.—The unit of resistance is the ohm. It is defined as the resistance of a column of mercury one square millimetre in cross sectional area and 106 centimetres in length.

Opalescence.—The property of certain kinds of glass which renders it a diffuser of light by reason of its containing small white particles which reflect the rays of light as they pass through.

Performance Curves.—The performance of lamps or a class of lamps is the information as to their operation under different conditions. The information is usually put in the form of curves showing the variation of voltage, current, resistance, power consumption, efficiency, and life, with candle-power all expressed in percentage of normal efficiency values.

Photometer.—A photometer is a device used to compare the candle-power of different light sources.

Photometric Curves.—(See Distribution Curves.)

Potential.—(See Voltage.)

Power.—The rate of doing work or the rate of dissipating energy. The units of power are the horse-power and the watt.

Reduction Factor.—The reduction factor of a light source is the ratio of the mean spherical candle-power to the mean horizontal candle-power. It is usually less than unity, and is commonly expressed as a percentage or as a decimal. It is seen from the definition that the mean spherical candle-power can be obtained by multiplying the mean horizontal candle-power by the reduction factor.

Reflector.—Appliance or lamp accessory designed to accomplish a twofold purpose. It redirects the light flux from the lamp so that it may be utilized most efficiently, and conceals the lamp so that the eye is protected from the intense brilliancy of the tungsten filament of the lamp.

Reflection.—Reflection occurs when rays of light are projected upon a surface and are thrown back from it. Light is reflected in three ways: *regularly*, *diffusely*, and by *spread reflection*.

Reflection Coefficient.—(See Coefficient of Reflection.)

Refraction.—When rays of light pass through a plate of clear glass or other transparent medium, refraction occurs. The ray undergoes a change in direction, the magnitude of which depends on the relative densities of the medium through which the ray passes and the surrounding air. When the ray leaves the medium it again changes its direction.

Regular Reflection.—Regular or specular reflection occurs when a beam of light falls upon a highly polished surface. The familiar law, the angle of incidence is equal to the angle of reflection, applies to this type of reflection.

Reflectors which follow the law of regular reflection include those having mirrored and polished metal surfaces. These afford a high degree of light control. The surfaces of the reflectors may be shaped so as to produce high concentration, a wide distribution, non-symmetrical distribution, etc., without any difficulty. In fact, if the commercial lamps were point sources these reflectors would have practically perfect light control. (See page 28.)

Resistance.—Resistance is the property of an electrical circuit which opposes the flow of a current through the conductor. The *ohm* is the unit of resistance.

Saturation of Colour.—The degree of freedom from admixture with white. As white light is added to a coloured light the saturation decreases until when the hue entirely disappears the saturation is zero. White, therefore, is the limiting colour, having no hue and zero saturation.

Selective Radiation and Reflection.—Some materials transmit and reflect light selectively—that is, they transmit a predominant of some particular colour. Thus, a green glass transmits mostly green light and largely absorbs the other colours. A red glass transmits mostly red light. Polished gold reflects chiefly yellow light, etc.

Shade.—An appliance the chief use of which is to diminish or interrupt the flux of light from the lamp in certain directions where this flux is not desirable. The function of the shade is commonly combined with that of the reflector. Reflectors are often erroneously called shades.

Spectrum.—Daylight and artificial light may be broken up into their various component parts or colours by means of a prism. The arrangement of colours produced by this analysis is called the spectrum. The principal colours of the spectrum are violet, indigo, blue, green, yellow, orange, and red.

Specular Reflection.—(See Regular Reflection.)

Spherical Candle-Power—(See Mean Spherical Candle-Power.)

Spherical Reduction Factor.—(See Reduction Factor.)

Spread Reflection.—The term spread reflection is sometimes used to designate specular reflection having a diffuse component such as is obtained from an aluminium surface. There is a breaking up of the beam, but with a certain direction to the scattered rays.

Reflectors which follow the law of spread reflection include satin-finish prismatic reflectors, aluminized metal reflectors, and satin-finish or depolished mirror reflectors. Such surfaces occupy a position about midway between the specular and diffuse reflecting media. They afford a greater degree of light control than diffuse reflectors, but a lesser degree than specular reflectors.

Transmission.—Transmission may be defined as the passage of light through a medium.

Tungsten Lamp.—The most efficient form of incandescent lamps. The filament of this lamp is made of metal tungsten. The average efficiency of the lamp is about one watt per candle.

Utilization Factor.—(See Efficiency of Utilization.)

Vertical Distribution Curves.—A polar curve representing the luminous intensity of a lamp or lighting unit in a plane passing through the axis of the unit and with the unit at the origin. In the case of incandescent lamps it is assumed that the vertical distribution curve is taken with the tip downward.

Visible Spectrum.—That portion of the spectrum which is visible—that is, capable of producing a sensation in the eye.

Visual Acuity.—The ability of the eye to distinguish fine detail in contradistinction to the seeing of ordinary objects which are observed by differences in light and shade. Visual acuity, for example, is the measure of ability to read type, etc., but has little to do with the seeing of persons, buildings, or other ordinary objects.

Volt.—The volt is the unit of electro-motive force, and is defined as an electro-motive force of such magnitude as to cause a current of one ampere to flow through a conductor having a resistance of one ohm. Volts equal watts divided by amperes.

Voltage.—Electrical pressure measured in volts.

Watt.—The watt is the unit of electric power, and is represented by a current of one ampere under an electro-motive force of one volt. Volts multiplied by amperes gives watts.

Watt-Hour.—The unit of electrical energy, the amount of energy consumed when one watt of power is maintained for one hour. It is the product of power and time.

Watts per Candle-Power.—Indicates the amount of electrical power necessary to produce unit luminous intensity. The efficiency of an incandescent lamp is usually expressed as watts per mean horizontal candle-power or mean spherical candle-power, ordinarily called *watts per candle.*

Watts per Square Foot.—The watts of the lamp illuminating an area, divided by that area in square feet, is the watts per square foot.

Working Plane.—The working plane or plane of reference is the plane on which the work is performed, and which, therefore, must be adequately and satisfactorily illuminated.

Wattage Rating.—Lamp sizes for interior illumination are now most commonly given in the watts consumed when operated at their rated voltage.

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